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ORIEL MICROFADING TESTER (MFT): A BRIEF DESCRIPTION

JAMES DRUZIK

ABSTRACT– The Oriel Microfading Tester was developed by Paul Whitmore at Carnegie Mellon University in the period 1994 to 1996 and has since been implemented in more than a dozen institutions worldwide. The technique, using an intense light source, employs a user-selected time interval to automatically collect a series of reflectance spectra, and derive from them a full complement of colorimetric quantities. These quantities may then be plotted to show the color change kinetics of selected colorants on artifacts. Thus it combines the features of fiber-optic reflectance spectrophotometry (FORS) with traditional accelerated light aging. This article will describe how the method works and how data is interpreted to identify particularly light-sensitive areas and inform decisions on risk assessment and management. Other strengths and weakness of the technique will be suggested that need be kept in mind during interpretation.

TESTER DE MICRODECOLORACIÓN (MFT) ORIEL: UNA BREVE DESCRIPCIÓN: RESUMEN – El Tester de Microdecoloración Oriel fue desarrollado por Paul Whitmore en Carnegie Mellon University durante el periodo de 1994 a 1996 y desde entonces se ha utilizado en más de una decena de institutos en todo el mundo. La técnica, de aplicar una fuente de luz intensa, utiliza un intervalo de tiempo seleccionado por el usuario para recolectar automáticamente una serie de espectros de reflectancia y obtener de ellos un complemento completo de valores colorimétricos.   Estos valores luego pueden graficarse para indicar la cinética del cambio de color de los colorantes seleccionados en los objetos.   De este modo se combinan las características de la espectrofotometría de reflectancia de fibra óptica (FORS, por sus siglas en inglés) con el envejecimiento acelerado tradicional por exposición a la luz. En este artículo se describirá cómo funciona el método y cómo se interpretan los datos para identificar áreas particularmente sensibles a la luz y para informar decisiones sobre evaluación y gestión de riesgos. Se sugerirán otras fortalezas y debilidades de la técnica para tener en cuenta durante la interpretación.

1. INTRODUCTION

The long history of light-fastness testing has been briefly compiled elsewhere (Druzik and Eshoj 2007), but dates from as early as 1733. By the late 19th century artists' materials were a serious topic of scientific study and reference (Church 1892). Yet the first study that took on a decidedly modern

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approach was the work of Russell and Abney in 1888 with their monumental work *Action of Light on Watercolours* (Russell and Abney 1888). By the 1930's recommendations on illumination levels for works of art began to appear in the literature (Feller 1964), and testing became common. Ultimately, natural light exposures were augmented by accelerated light aging derived from industrial applications and a review of the work of Robert Feller and Ruth Johnston-Feller illustrate this very well (Whitmore 2002). If one is prepared to give accelerated light aging enough time, any colorant except for those that are fully inert, can be induced into change and placed within a range of light stabilities that range over 3-4 orders of magnitude. For simplification and control, these studies are typically carried out on newly prepared materials. But for a number of reasons, testing newly prepared materials will not accurately predict naturally-aged samples even when they are of identical chemical composition. So a method is needed that could test colorant systems on real artifacts, of any age, in a "virtually" non-destructive manner, do it reasonably fast, and focus on the most vulnerable examples. Two approaches were described independently by Pretzel (Pretzel 2008) and jointly by Costain (Costain, Michalski et al. 1995) and Michalski (Michalski 1997), but the first identification of a technique that would later be called "microfading" appeared in a lab book entry written by Paul Whitmore and dated, September 21, 1994. The method was formally published several years later (Whitmore, Pan et al. 1999).

This article will describe the operation of the microfading tester and how it has evolved since then. Because 12 of 14 working instruments have been built from the Oriel implementation and are

2. HARDWARE DESCRIPTION

The fundamental components of a microfading technique are rather straightforward to deduce. A powerful, yet compact light source is needed. It must be inherently stable or contain a feed-back loop to insure that stability. It requires a means to filter the light path to match certain requirements. It must have a convenient method to convey its light output to nearly any geometric surface orientation. The reflected light must then be collected and passed to a spectrophotometer, and the spectrophotometer should save its spectra to a file structure on a computer. This is illustrated in figure 1.

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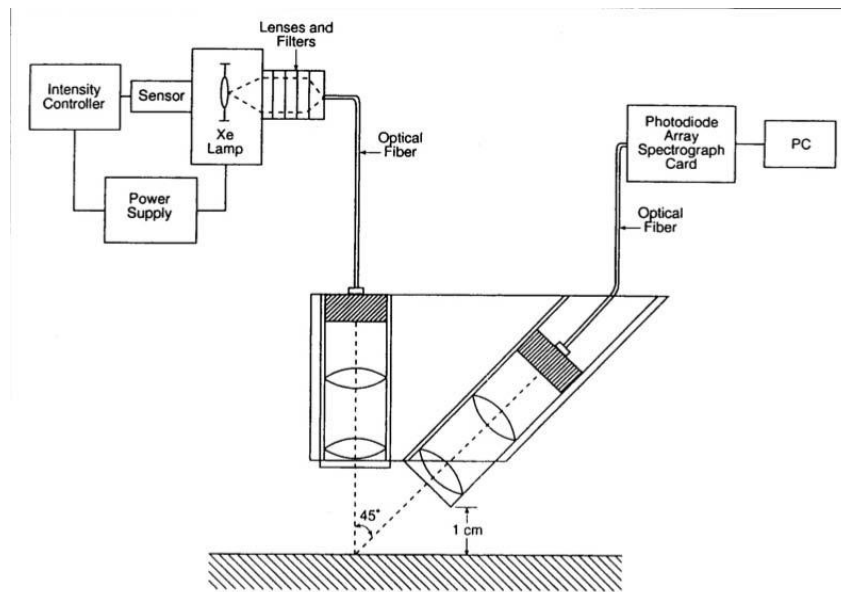
Figure 1. Schematic of the Oriel Microfading Tester. Shown with permission of the
Journal of the American Institute for Conservation, Vol. 38, No. 8.

2.1 LIGHT SOURCE

The Microfading Tester (MFT) light source should be as compact and intense as possible. This limits the
options to a spark source xenon lamp (fig. 2). The lamp has no integrated reflector but a mirror behind
increases the output that will exit the lamp housing by 60%. Light passes through a condenser lens
assembly, water filter, hot mirror and UV filter, exiting through a quartz fiber (fig. 3). All these filters may
be used in combination, only some of them used, or even others not specified. The water filter and hot
mirror remove most infrared wavelengths and reduce the thermal transmission from the source to the
fiber. Since a xenon source is richer in shorter wavelengths than common museum illuminants intended
for the display of light-sensitive objects, a third filter insures that these ultraviolet wavelengths are cut
off.

The xenon lamp is nominally operated at 75 watts but is automatically adjusted for stability. The user
may also adjust lamp wattage – a feature Christopher Maines has exploited at the National Gallery of
Art by dropping the lamp to 40 watts for artifacts considered to be especially sensitive.

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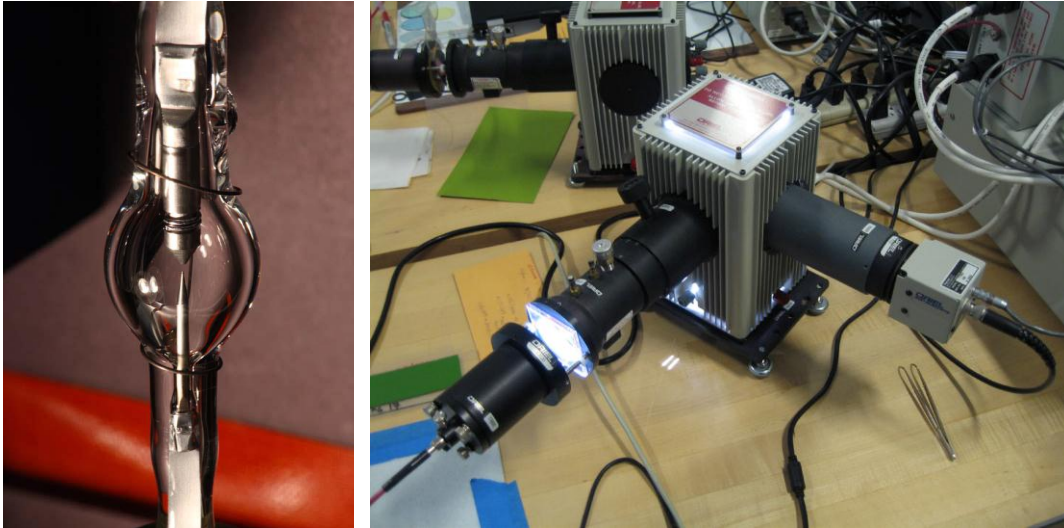
Figure 2 (left). 75 watt xenon lamp. Figure 3 (right). The xenon lamp housing with filter assembly (left tube assembly). The right side tube terminates with a photodiode array detector used to provide feed-back luminosity to the power supply.

2.2 MAIN FRAME ELECTRONIC

To the right side in figure 3 a second tube is seen exiting the lamp housing. This contains a photodiode array detector and a small aperture which, when combined with control electronics insures the highest luminous flux stability feasible during daily operations. It also provides stability during periods when a series of related materials may be tested together and the data needs to be kept as comparable as possible. Lamp wattage and amperage are modified with this feed-back loop as the digital exposure controller interfaces and controls the lamp power supply. Three portable implementations of the MFT at the Netherlands Institute for Cultural Heritage (ICN), the Getty Conservation Institute (GCI), and the Canadian Conservation Institute (CCI) have been built to eliminate the lamp stabilization electronics and use a simpler power supply with the same xenon lamp. This compromise works adequately for short studies but has no mechanism to hold lamp output stable for longer periods of time.

2.3 PROBE

The probe directs light from the source to the tested surface in a non-contact, 0/45° geometry. Figure 1 illustrates two convex lenses for each lens tube. In actual practice three possibilities have been used.

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Planoconvex, achromat doublets, and in a method first used at the Museum of Modern Art (MOMA) by Christopher McGlinchey, with no lenses at all. In the MOMA probe a single 100 micron fiber applies light normal to the surface and a cluster of six pick-up fibers return scattered and reflected light back to the spectrophotometer. Figure 4 a-c show three variations of the probe with and without a pen camera to monitor focus. Figure 4a is most common, figure 4b shows the lensless probe, and figure 4c is the probe built by Bruce Ford, Australian National Museum (ANM), where the camera can be located at right angles on either side of the source/spectrometer axis.

The luminous flux from the source can vary from about 250-1100 millilumens for spot diameters estimated to be from 0.2 to 0.4 mm. Since lux is defined as lumens per meter squared, these produce rather high lux exposure equivalents but to vanishingly small areas. Five to over 16 megalux can be delivered producing meaningful data in as little as 10 minutes.
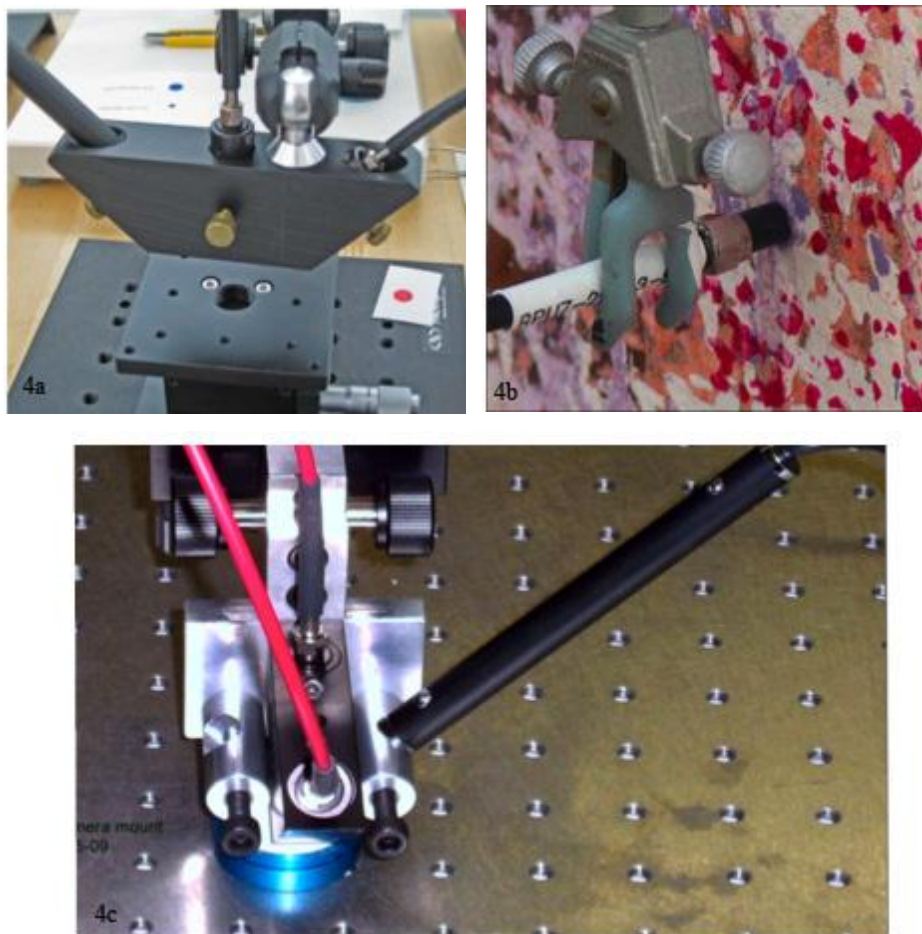

Figure 4a-c. Various probe designs to direct the xenon light to the surface being measured.

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2.4 INTERNAL STANDARDS

With such high light fluxes it is not unreasonable to assume that the rate of color change would proceed faster than during ambient levels of exposure. For this reason attempting to calculate dose/effect (lux hours) and applying it directly to objects and their most sensitive colorant regions is not realistic and may lead to bizarre results. Rather, calibration is achieved by running internal standards and assuming that a colorant that changes similarly to a particular standard under these conditions will do the same under ambient ones. There are conditions when this assumption may be false and we shall outline them briefly in Section 5. For the time being suffice it to say that the internal standards used most often are the ISO Blue Wools. Michalski has frequently published the light-induced responses of these standards in the dose needed to achieve a "just noticeable change". Just noticeable difference is used here to mean, in a simplified manner, the equivalent to a just perceptible color change (fade, darkening, hue shift) visible to an observer with average color perception under ideal viewing daylight conditions. The term is more formally defined by the CIE but is outside the scope of the present paper. Two technical reports often cited that embody these data have been published by CIE and IES (IESNA 1996; CIE 2004). As is the case for nearly all manufactured products, the ISO Blue Wools may need to be checked from time to time to determine if any manufacturing changes have impacted their performance.

2.5 SPECTROPHOTOMETER

The light reflected back from the surface is passed via a second quartz fiber to the spectrophotometer designed to handle fibers input. The instrument selected by Whitmore was, and still is, built by Control Development although it has gone through at least three major hardware re-designs. It is still employed by most users.

3. SOFTWARE DESCRIPTION

There are two levels of software control. The first operates the spectrophotometer spectral acquisition and conversion into colorimetric parameters that are then included and saved in a special header with each spectral file. The second level has tended to be written by individual users and takes portions of the colorimetry for plotting and subsequent interpretation. The user selects the colorimetry and data acquisition parameters. This is usually, but not necessarily limited to an illuminant of D65, 2° or 10°

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standard observers, CIELAB color space. In addition one or more of the three color difference equations may be utilized during interpretation. Spectral acquisition intervals at 1 or 2 minute intervals are most common.

4. INTERPRETATION

The original intent was to create an instrument that would identify objects containing light sensitivity on some portion of the artifact that is equivalent to ISO blue wool 1-3. In most discussions of preventive conservation and risk management, the most sensitive category comprise these three (CIE 2004). For ISO blue wool 1 a "just noticeable difference" is expected under typical museum light levels at a dose on or about 300,000 lux hours; ISO blue wool 2 at 900,000 lux hours; and ISO blue wool 3 at 2.7 million lux hours. Except for blue wool 1 these are often rounded up. These data are averaged values Michalski derived from work conducted in the 1950's and 1960's. Current work at GCI and CCI are seeking to establish if those values are still relevant for currently manufacturer ISO Blue Wool products. Those sound like large doses of light exposure, and indeed that might be, but they are tiny compared to the exposures that can accumulate over decades and centuries, not at 50 lux but at hundreds or even thousands of lux. It is remarkable that any colorant that is equivalent to ISO blue wool 1 could ever have survived from the 19th century let alone earlier. But the tendency to sequester hand-colored prints, drawing and early photographs in albums where many of them never literally "saw the light of day" has insured their survival with minimal modification. Finding them and providing highly restrictive loan and exhibition limits, even creating a category of minimal tolerance for exposure damage (Brokerhof 2008) has become a high value operation in some institutions.

The MFT can easily detect a colorant located within the ISO blue wool 1-3 range. Figure 5 illustrates an example of a blue pastel stick taken from the studio of Georgia O'Keeffe applied to Whatman filter paper and graciously provided by the Georgia O'Keeffe Museum in Santa Fe, New Mexico. Previously, ISO blue wools 1-3 were run and ΔE is plotted versus time and represented by square symbols. Blue wool 1 is the highest, blue wool 2 is intermediate, and blue wool 3 the lowest. Mengs blue is represented by the dark circles. Measurements were taken at 60 second intervals for 30 minutes. Depending on what one wants to achieve in the interpretation, Mengs blue may be classified as equivalent to blue wool 2 because it shows a just noticeable fade *under ideal laboratory viewing*

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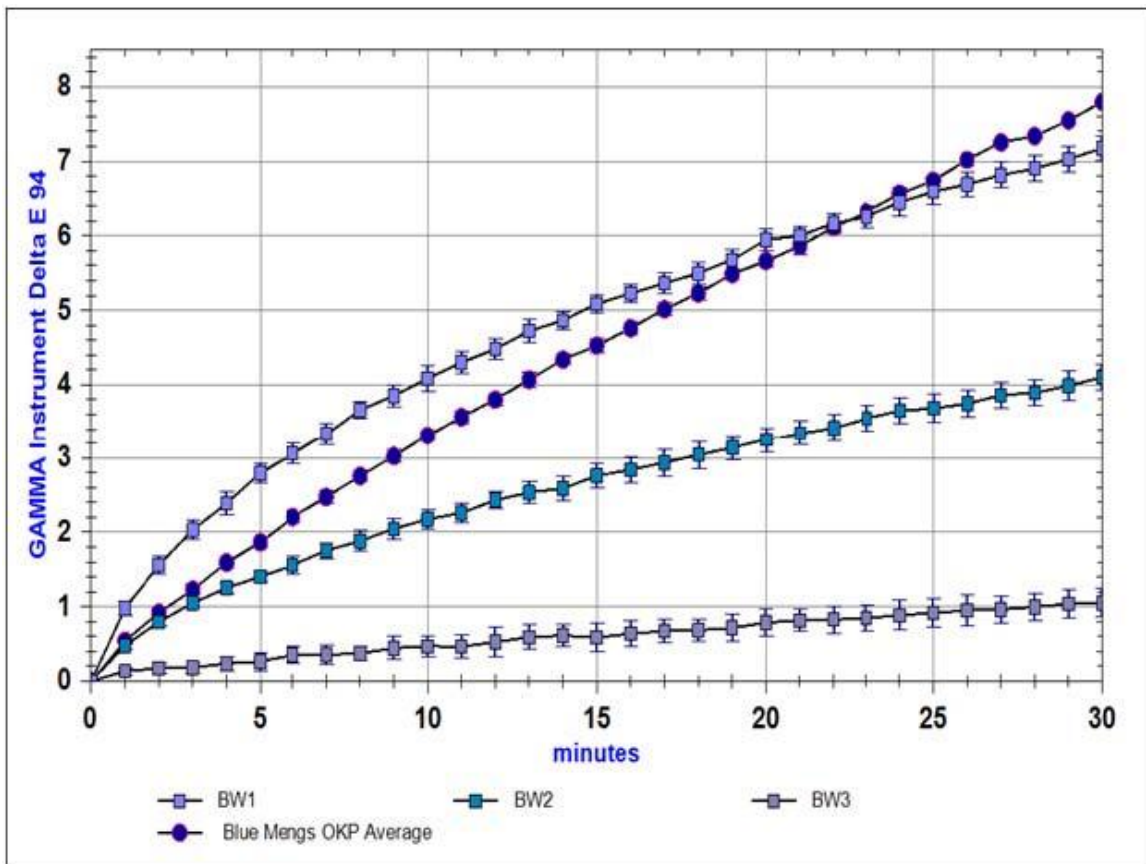
Figure 5. Mengs blue soft pastel from the studio of Georgia O'Keeffe compared to ISO Blue Wools 1-3.

conditions closest to that standard after 2-3 minutes or as blue wool 1 because *under gallery lighting in complex compositions* color change is much harder to see and closer to blue wool 1 after 15 minutes. Regardless, blue wool 1 or 2 means that Mengs blue is highly vulnerable to light-induced damage. It is beyond the scope of this short article to further analyze this example but we shall suggest for the time being that because ΔE for Mengs blue is also nearly a straight line and its overall chroma, as ΔC*, is regressing to a*=b*=0, its vulnerability is best served by assuming the higher sensitivity possible under all exposure conditions. These are the kinds of clues we look for during light aging.

Figure 5 shows that the color difference of Mengs blue was plotted using the 1994 CIE color difference equation. More commonly the 1976 equations are employed because it is easier to correlated ΔE* or DE76, with older literature but there are advocates suggesting that both the DE94 and DE2000 equations should be used in preference to the old approach. In a following article by Druzik and Pesme

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this subject will be more thoroughly explored.

It is a matter of personal philosophy whether or not users of MFT-derived information are content using it to spot light-sensitivity and leave it at that, or take the next step and build exhibition display and loan restrictions policy around it. Both positions can be easily defended. The next section will outline just a few of the possible conditions under which MFT results could significantly over – or under-estimate light sensitivity.

5. LIMITATION AND STRENGTHS

When might the MFT under – or over-predict light sensitivity? The MFT compares favorably with other accelerated light aging instruments (Whitmore, Pan et al. 1999), yet it does have unique attributes the user should frequently take into consideration. The MFT is very precise and virtually invisible because the location for testing is so small. This means it is vulnerable to the same non-representationality as any other micro-sampling technique. This is particularly easy to see with watercolors. The density of pigment particle distribution will influence the apparent sensitivity. Both light washes and heavier body color will be capable of displaying smaller increases in ΔE* than a mid-density particle distribution.

Secondly, one must consider the testing location as an *entire system* not an isolated pigment with any single part, or all parts, capable of independent or inter-related changes. It is not uncommon for the paper substrate to show a spectral increase in the 400-500 nm range due to cellulose "bleaching". The author has even seen "bleaching" in 100-years only white, presumably inert soft pastels, on Whatman filter paper. From testing we know lightening reactions on fresh Whatman filter paper are almost non-existant leaving one with the hypothesis that it is the aged pastel binder that may be lightening. As good as the ISO Blue Wool samples are, they are a woven textile and the position of the light beam and its geometry with respect to the weave may influence the outcome for the internal standard and hence all the assessments based upon it.

The MFT was created to locate the presence of sensitive colorant systems on artifacts. As sensitivity increases predictability becomes more problematic. Some colorants used towards the late 19th century for hand-tinting photographs are aromatic compounds with highly delocalized electrons that take very little energy to instigate transitions. It is not improbably for the energy of a single absorbed photon to participate several times between primary photo-induced and secondary reactions. If the photon flux is

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high this could accelerate overall change, keeping to the original ambient light aging mechanisms. Thus there is a risk of assuming a higher sensitivity than there may be for chromophoric systems like these.

We assume that light damage follows a reciprocity-type relationship but almost every known photographic process exhibits some reciprocity "failure" at the exposure extremes. The use of the term "failure" is traditional but regrettable, since the only thing that is really failing is the expectations of the photographer. There is no reason why, for pigments and dyes, reciprocity cannot behave more or less linearly over small line segments of a greater dose/effect *curve* and what we should be looking for ultimately are calibration curves that express these dose/effect relationships rather than a purely linear simplification.

Local environmental conditions modify fading behaviors. We know from the work of David Saunders (Saunders and Kirby 2004) that for some materials relative humidity plays an important role in their light-sensitivity. Some researchers have reported elevated temperatures at the spot and these are bound to have an influence on secondary reactions that may play out over time. Patricia Cox Crews in her work on dyes fading has called attention to the role of the particle's physical state of agglomeration which impacts the rates of oxygen diffusion (Cox Crews 1987). Feller pointed out that reactions proportional to the square root of intensity, while never having been reported in conservation, nevertheless remains something to keep in mind (Feller 1994).

Lastly, we'll remind the reader that the spectral power distribution of the MFT xenon lamp is not the same as that used to illuminate most light-sensitive artifacts. The source is filtered to remove wavelengths shorter than 400 nm but it is still a light source with a correlated color temperature between 5500 and 5700K. This gives it a higher proportion of shorter visible wavelengths than tungsten and halogen sources.

Given these limited observations, one could question how reliable MFT methods are for prediction. Preventive conservation often takes the position that risk management decision-making is nearly always limited by the concept of "bounded rationality". That we, as humans, seek at all times to make rational decisions that are frequently beyond the computational scope of our abilities and are too complex to reliably predict anything with accuracy. Our decisions then evolve over time in the form of successively better approximations as the tools for making such approximations improve. Knowing these weaknesses, the MFT can still be validly used to set and enforce policy that may have had even less

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rationality afford for setting limits in the past. We all know that once paper-based objects were considered universally light-sensitive when almost nothing about their fiber or media selection pointed to unusually high irreversible light interaction. Taking a careful materials-oriented approach allowed us to partition out the more sensitive from the lesser sensitive ones. Perhaps, in the future the major limits of MFT will be better understood and give us more precision than we now have.

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JAMES DRUZIK is a Senior Scientist at the Getty Conservation Institute, where he has worked since 1985. His research interests have been highly varied over the years and have included image processing (Caltech/JPL), the origin and fate of anthropogenic oxidant air pollutants and particulates in museum environments and their control technologies in conjunction with Glen Cass and Paul Whitmore (Caltech). In 2002, he began a large multi-disciplinary research program examining better techniques for safer

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museum lighting in collaboration with Carl Dirk of the University of Texas at El Paso. Also in 2002, he assembled his first of three optical instruments based upon a design published by Paul Whitmore at Carnegie Mellon University for near-real time color change kinetics assessments on works of art in a virtually non-destructive manner. His group now routinely carries out assessment of light sensitivity for the Getty Research Institute, the J. Paul Getty Museum, and the Georgia O'Keeffe Museum in Santa Fe, New Mexico. He has previously worked at the Los Angeles County Museum of Art and the Norton Simon Museum in Pasadena, California. Druzik holds a B.S. in Chemistry.

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COMPARISON OF FIVE MICROFADING TESTER (MFT) DESIGNS

JAMES DRUZIK AND CHRISTEL PESME

ABSTRACT - In April 2009, the Netherlands Institute for Cultural Heritage (ICN) convened a meeting in Amsterdam to discuss the status of microfading research. It was clear that while approximately 12 of the 14 microfaders worldwide were built using the Whitmore design, considerable innovation had also taken place. In the absence of round robin testing at the time, concerns over the comparability of these innovations led the authors to purchase the parts needed to recreate five instruments for a side-by-side comparison. In this manner the instruments could be tested holding variables related to user experience and protocols constant. A set of seventeen test colorants were selected that included both new and historical materials. All three CIE color difference equations used in making color change assessments were evaluated. The question was asked, "How often would the microfaders facilitate an assessment to within ½ step of an ISO blue wool step in equivalent lightfastness?" As a result of those tests more than 12,000 spectra were collected and analyzed. The results stood out in good agreement and our ½ step criterion was matched or exceeded 70% if the time and was matched or exceeded to 1 full step 95% of the time. This paper describes the details of those experiments.

COMPARACIÓN DE CINCO MODELOS DE TESTER DE MICRODECOLORACIÓN (MFT): RESUMEN – En abril de 2009, el Netherlands Institute for Cultural Heritage (ICN) convocó a una reunión en Amsterdam para discutir el estado de la investigación sobre microdecoloración. Estaba claro que si bien aproximadamente 12 de los 14 microdecolorantes mundiales se construyeron utilizando el modelo Whitmore, también se había desarrollado una innovación significativa. Ante la ausencia de la planificación round robin en ese entonces, la preocupación de poder comparar estas innovaciones hizo que los autores adquirieran las partes necesarias para recrear cinco instrumentos para realizar una comparación paralela. De esta manera los instrumentos podrían ser probados manteniendo variables relacionadas con la constante de la experiencia del usuario y los protocolos. Se seleccionó un conjunto de diecisiete colorantes de prueba que contenían materiales nuevos e históricos. Se analizaron las tres ecuaciones de diferencia de color CIE utilizadas para realizar las evaluaciones de cambio de color. Se formuló la pregunta: "¿Con qué frecuencia los microdecolorantes posibilitarían realizar una evaluación a ½ paso de un paso ISO blue wool con una resistencia a la luz equivalente?" Como resultado de esas pruebas se recolectaron y analizaron más de 12.000 espectros. Los resultados concordaron bien y nuestro criterio de ½ paso coincidió o excedió en el 70% de las veces y coincidió con 1 paso completo o

lo excedió en el 95% de las veces. Este ensayo describe los detalles de dichos experimentos.

1.   INSTRUMENTS

The operations of the Oriel-based Microfading Tester (MFT) are described fully in the introductory paper to this series by Druzik and need not be repeated here. We shall only define the nature of the differences in the MFT "models" we tested. Readers who want more information may also refer to Whitmore's earlier article (Whitmore, Pan et al. 1999). Consider the MFT as having two distinct versions. A bench top version with a full-featured power supply, separate lamp housing, filter assembly, and light output control electronics, and a portable model which combines the lamp with a simplified power supply in one box, adds a limited filter package to one side and drops the need for light stability and control altogether. The possibility of a functional portable MFT was shown by Han Neevel at the Netherlands Institute for Cultural Heritage (ICN) using an Ocean Optics Mikopack HPX-2000 light source. At GCI we modeled ours around a Newport 70529 Apex Fiber Illuminator. Figure 1 is a schematic illustration of the differences between the Whitmore bench top instruments and the portable variants.

Each of these two versions uses the same spectrophotometer and software but they may have three significantly different probes that focus the light to the surface that will be measured. One probe design uses the original four planoconvex lenses, the second probe substitutes four doublet achromat lenses, and the third does away with all lenses and employs a 6/1 bifurcated fiber optic. The first two probes employ a normal/45° reflectance geometry and the lensless probe is used for surface contact measurement. The lensless system was first used by Christopher McGlinchey at the Museum of Modern Art. The bifurcated fiber optic has a single 100 micron fiber channeling light from the lamp and joins with six other fibers in a cluster at the flat end of the fiber cable. Light passes through the central fiber, is reflected from, absorbed by, and scattered around the substrate and enters the adjacent six fibers that connect to the spectrophotometer – all within an area less than one half a millimeter in diameter.

These probe modifications are not without unique optical ramifications. Achromat lens are designed to solve a problem with chromatic and spherical aberration. With chromatic aberration a normal lens fails to bring all wavelengths into focus at a single point. The phenomenon is called, in optics, dispersion, in which the phase velocity of a wave depends upon its frequency. The solution is often to create lenses of balancing dispersions. In this case the achromat selected is a doublet made by cementing two different types of glass together. This design results in a tighter focus. Both the planoconvex and achromat spots
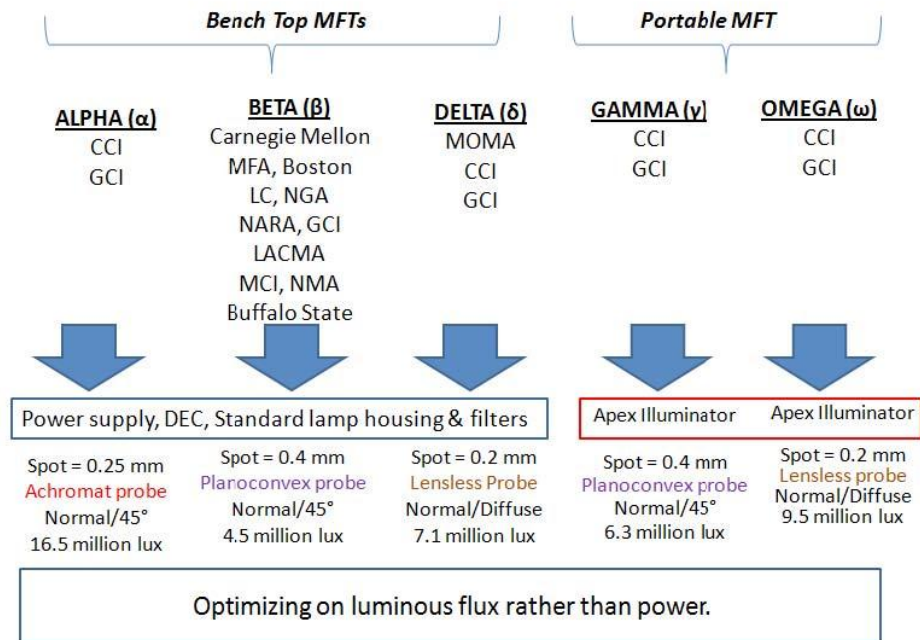
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Figure 1. Schematic illustrating the five different instruments, which institutions uses each variation, and a comparison of spot size, luminous flux, and measurement geometry.

appear white but if they are enlarged one actually sees minor colored rings with the planoconvex lenses. The smaller spot size with these achromats result in a reduced spot area and thus higher lux equivalent exposures. At equal luminous flux, all else being equal, the planoconvex lenses will deliver about 40% the lux intensity of the achromats.

The situation is a little more complicated for the bifurcated fiber having no lenses. The Apex illuminator positions only a single pair of aspherical lenses between the xenon arc and the UV filter, hot mirror, and quartz fiber. The standard bench top configuration sports an adjustable aperture condenser lens. For the same 200 micron fiber used with the lensed probes this would not present a problem, but the bifurcated probe is only 100 microns in diameter. This insures some loss of bandwidth. The correlated color temperature measured with a PR-670 spectroradiometer from Photo Research ranges from 5000-5600K for the bench top instruments but only 3000-3300K for the Apex illuminator coupled with the bifurcated fiber. The difference in the spectral power distribution was expected to manifest itself in the final classifications of light sensitivity.

The five instruments were named Alpha, Beta, Gamma, Delta and Omega. Because the light apertures have three different diameters from instrument to instrument and lamps of different ages and performances - given that lux is defined as lumens per square meter - the five had different photon flux

outputs in lux. We also varied the operating wattage as might occur under realistic operations. The output in lux for these evaluations were then: Alpha: 16.5 Mlux, Beta: 4.8 Mlux, Gamma: 6.3 Mlux, Delta: 7.1 Mlux, and Omega: 9.5 Mlux. Figure 2 shows a probe with planoconvex or achromat lens locations indicated.
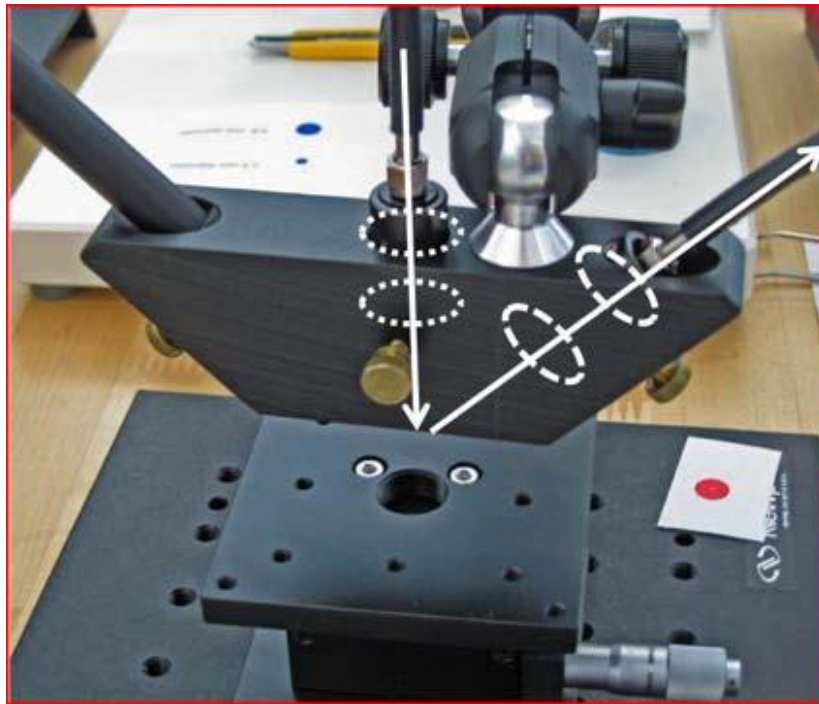
Figure 2. The probe is a solid machined block with one hole drilled vertically in the center and two holes at 45°angles. The dotted white circles show lens locations for the incident light path and the dashed circles are lens location for reflected light. The tube at the opposite 45° hole is for a small medical camera used for alignment and focus.

2. TEST MATERIALS

Table 1 lists the materials to be tested interspersed with copious runs of ISO Blue Wools 1-3 as internal standards. All samples were run with four replicates on each instrument of 30 spectra each at collection intervals of 60 seconds for a total of 30 minutes per run. The first eight colorant systems were taken from the GCI reference collection and contained two watercolors, two gouaches, and both pre-faded and unfaded black and purple construction paper. We had previously microfaded 100+ soft pastels left in Georgia O'Keeffe's studio after the estate passed to the Georgia O'Keeffe Museum in Santa Fe, New Mexico that had been applied to Whatman #1 filter paper. We pick three of the most light-sensitive

from the manufacturers, Weber (USA), Le Franc (France), and Mengs (Germany). Concluding the list was three early 20th century dyes on silk from a sample dye book in the collection of the Getty Research Institute from J.R. Geigy A.-G., and three dyes on cotton from a similar dye book produced by Agfa-Griescheum. Table 2 is the expected distribution of light sensitivities prior to testing.

Table 1.   List of materials tested

Materials	Preparation	Origin
Wild Rose (Martin Watercolors)	Wash on Whatman #1	GCI Ref. Coll.
Rose Bengal (Winsor & Newton, Gouache)	Airbrush on drawing paper Rhodamine/aluminum lake Fluorescent dye	GCI Ref. Coll.
"Rose Malmaison" (Winsor & Newton, Gouache) NMA	Wash on drawing paper BON arylamide red 1,2-dihydroxyanthraquinone	GCI Ref. Coll.
Alizarin Crimson (Winsor & Newton, Watercolors)	Airbrush on drawing paper BON arylamide red 1,2-dihydroxyanthraquinone	GCI Ref. Coll.
Purple construction paper	Dyed "construction paper"	GCI Ref. Coll.
Faded Purple construction paper	Dyed "construction paper"	GCI Ref. Coll.
Black construction paper	Dyed "construction paper"	GCI Ref. Coll.
Faded Black construction paper	Dyed "construction paper"	GCI Ref. Coll.
O'Keeffe Pastel: Emerald Green, Weber (USA)	Dry application on Whatman #1	GOK studio
O'Keeffe Pastel: Granance Cramoise, Le Franc (France)	Dry application on Whatman #1	GOK studio
O'Keeffe Pastel: Blue, Mengs (Germany)	Dry application on Whatman #1	GOK studio
J.R Geigy A-G. Acid Green	Dyeing on weighted crepe de Chine	GRI circa 1930's
J. R Geigy A-G. Erio Cyanine A	Dyeing on weighted crepe de Chine	GRI circa 1930's
J. R. Geigy A-G. Violet Diphenyl TS 0.5%	Dyeing on weighted crepe de Chine	GRI circa 1930's
Agfa-Griescheum. Zambesi Red B 2.5%	Dyeing on cotton	GRI ca. Early 20th c.
Agfa-Griescheum. Primulin 1, 1%	Dyeing on cotton. (Flavonoid)	GRI ca. Early 20th c.
Agfa-Griescheum. Primulin 1. 5%	Dyeing on cotton (Flavonoid)	GRI ca. Early 20th c.

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Table 2.   Expected sensitivity distribution

≥ISO Blue Wool 1	ISO Blue Wool 2-3	≥ISO Blue Wool 3
Rose Bengal	Rose Malmaison (New)	Alizarin Crimson
Unfaded Black Construction Paper	GOK Le Franc Granance Cramoise	GOK Weber Emerald Green
Unfaded Purple Construction Paper	Agfa Zambesi Red	Agfa Primulin 1%
Wild Rose	Faded Black Construction Paper	Agfa Primulin 5%
GOK Mengs Blue	Faded Purple Construction Paper	
	Geigy Acid Green	
	Geigy Erio Cyanine	
	Giegy Violet Diphenyl TS	

3. ANTICIPATED CURVE SHAPES

Patricia Cox Crews reviews various types of curves from the work of Giles and relates his hypotheses for their shapes (Cox Crews 1987). Three curves shown in figure 3 are seen an estimated 95% of the time in microfading. Type I curves are thought to be dyes molecularly disperses throughout a substrate. Type II, which shows a rapid fall-off is attributed to dye/pigment aggregates with some molecularly dispersed colorant responsible for the initial rapid loss. Type III curves are attributed to larger aggregates with a fixed constant visual change that is oxygen diffusion limited. Whether or not the reasons for these shapes reported by Cox Crews apply to microfading behavior is unknown and outside the scope of this investigation. But when we encounter them, we expect their shapes to remain similar from instrument to instrument. Likewise we would theorize that if the behavior remained the same regardless of light intensity, the fundamental chemistry, in the limited way it can be tracked though kinetic colorimetry would also remain the same or similar. Figure 4 shows CIELAB color data a* and b* for unfaded purple construction paper confirming the similarity of the dose responses for four series of runs between 4.8 million and 16.5 million lux. Figure 5 illustrates where the curves would occur if we had internal standards that represented blue wools 3, 2.5, 2, 2.5, 2, 1.5, 1, and two levels above 1. In reality we have only 1, 2, 3 (and unfaded purple construction paper which will serve as our most light sensitive calibration standard). We call unfaded purple construction paper ">>BW1" and the halfway point ">BW1" although we could also have used the terminology BW0 and BW0.5 as well. There were potential candidates for standards that are more sensitive than BW1 but at the time of the study all

were far too sensitive to be used. We shall designate a tested material's ISO blue wool equivalency as its "nearest neighbor" curve after 30 minutes of exposure.
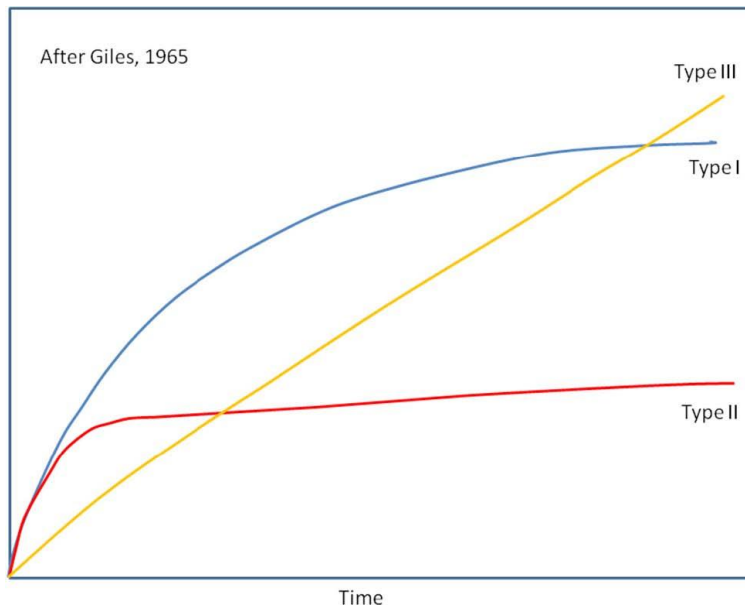

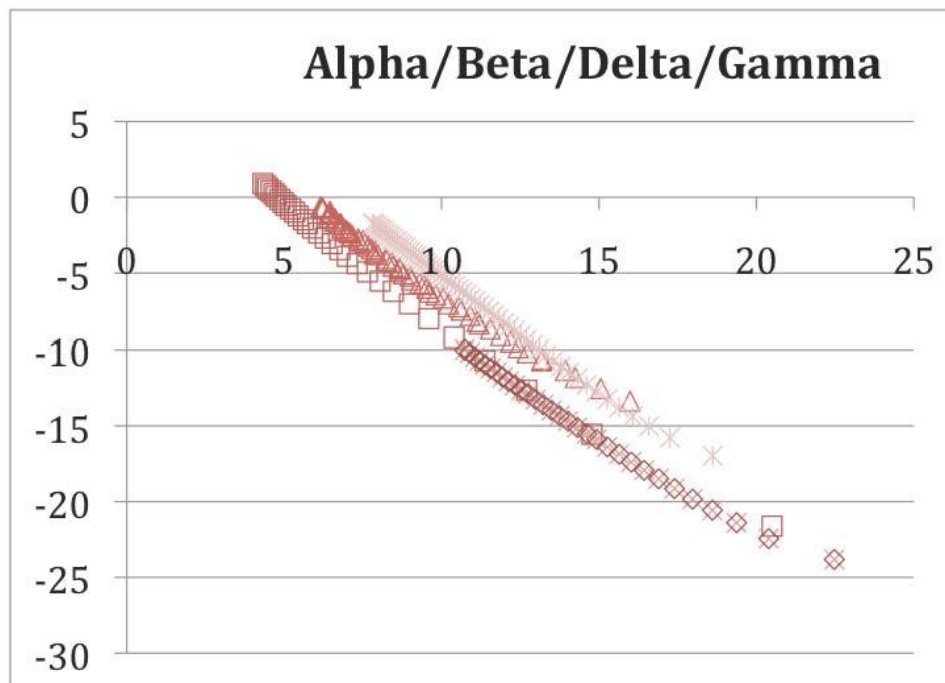Figure 3. Expected curve shapes for colorant systems (Patricia Cox Crews after Giles).

Figure 4. CIELAB a* (y axis) plotted versus b* (x axis) for unfaded purple construction paper at luminous fluxes ranging from 4.8 to 16.5 million lux.

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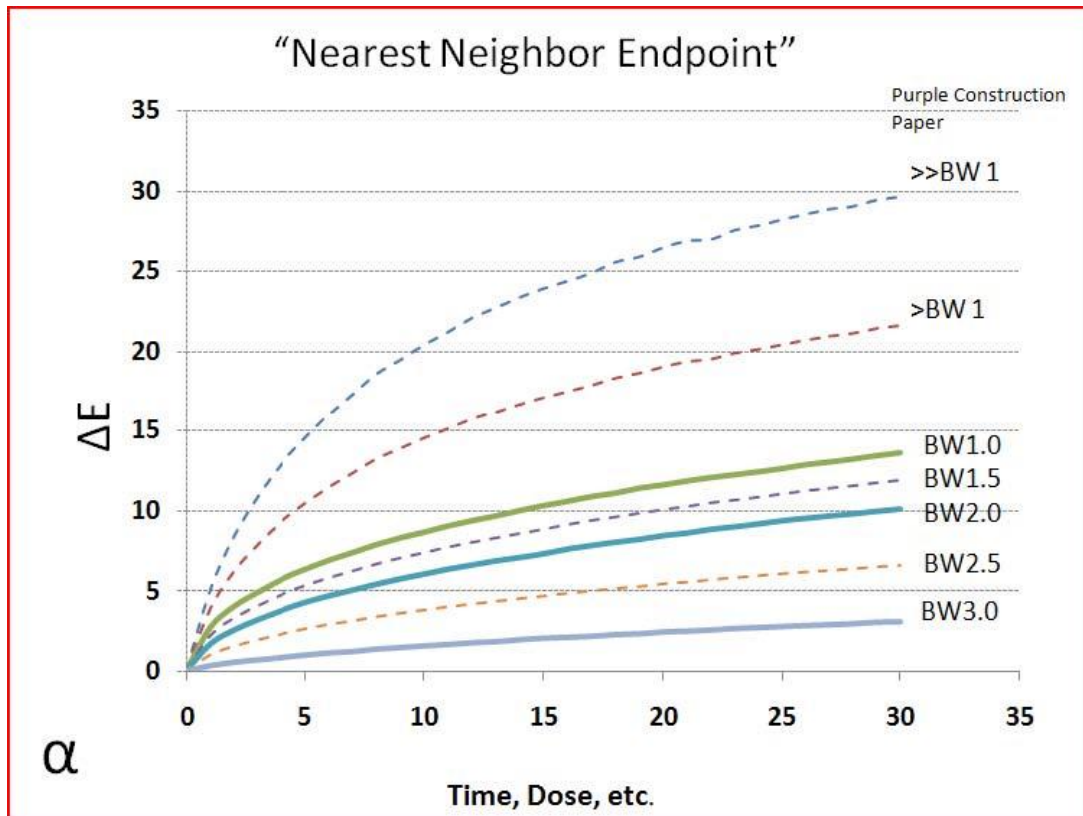
Figure 5. Endpoints for establishing ISO Blue Wool equivalency with tested materials.

4. RESULTS

4.1 AGREEMENT BETWEEN CIELAB COLOR DIFFERENCE EQUATIONS

It is assumed that the reader has a familiarity with basic colorimetry and CIELAB color space. Since it is beyond the scope of this paper to describe those topics fully, excellent discussions can be found in the literature (Berger-Schunn 1994; Berns 2000; Fairchild 2005). In 1976 the CIE published their first color difference equation to express the Euclidean distance between the L*, a* and b* coordinates.

$$\Delta E^*_{ab} = [\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}]^{1/2}$$

CIELAB color space was intended to be perceptually uniform but this goal in its creation was not strictly achieved (Fairchild 2005). To improve the uniformity of color difference measurements the CIE approved a modified equation, CIEDE94 that was recommended to replace CIEDE76 for industrial use in 1994.

Still more recently in 2000, a far more complex CIEDE2000 equation has been developed and Pretzel and Saunders have both begun using it in their conservation research (Saunders and Kirby 2004; Pretzel 2008). Notwithstanding these two researchers, for microfading color difference assessments there has

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been a general hesitancy to relinquish CIEDE76. The older equation has been a mainstay in conservation research making the idea of "backward compatibility" very attractive. Our study allowed CIEDE76 to float as the method *de rigueur* and asked if CIEDE94 or CIEDE2000 offered sufficient improvement to be recommended as a replacement.

Table 3 compares the assessments based on the three equations against four instruments and all seventeen colorants. The fifth instrument was added late in the study after we had already drawn our conclusions concerning the relative merits of the three equations from the first four instruments. The absence of DE76 and DE2000 in the column under the Omega instrument does not alter these conclusions but those conclusions do explain why we subsequently used DE94 when we included the Omega assessments in the final analysis.

It is probably not justified to go further than to draw general trends. The reasons are the following. We calculated color change kinetics on three equations, rounding up or down ISO blue wool sensitivity to ½ step intervals when comparing samples to their nearest blue wool internal standard. This was a subjective decision and influenced strongly by the cut-off time for the exposures. We chose 30 minutes because it appeared to treat the three most important curves shapes seen in figure 3 more accurately, but others may have chosen a shorter or longer exposure period. The nuances of the two more precise equations are blunted by the uncertainties in the risk assessment process. The two other restrictions are that the ISO blue wool scales are limited at the most sensitive end and several of our samples, as in real life, exceeded their range, and the MFT has restricted range below BW3.

Still, by assigning the values 0, 0.5, 1, 1.5, 2, 2.5, 3, and 4, we can draw some numerical inferences. Within a ½ blue wool step range, 95% of the assessments averaged over four instruments are in agreement whether based on curves derived from DE94 or DE2000. Assessment based on all three equations grouped within a range of ½ step averaged over four of the instruments, about half the time. For those instances where DE76-based assessments exceeded that ½ step range, the tendency was for DE76 to rank the samples as less sensitive than assessments based on either of the other two equations. The reason for this is not difficult to understand. DE94 and DE2000 calculate lower values for ΔE than does DE76 for most colors and in the case of blue colors this can be a large difference. When chroma is low, all three equations converge to similar values. Examining results in Table 3 for faded black construction paper one easily sees this effect. The curves for faded black paper did not change with color difference equation but the curve position relative to the blue wool curves did change resulting in an average DE76-based assessment of 2.3 while DE94 and DE2000 were 1.0 and 0.9 respectively. For this

reason we choose to recommend the use of DE94 because it is easier to implement than DE2000 and because for a small but significant number of samples it will render a more conservative evaluation of light sensitivity.

Table 3. Comparison of ISO Blue Wool assessments based upon light sensitivity calculated from three color difference equations. >BW1 means the sample possessed a sensitivity to light greater than BW1. <BW3 means the sample possessed a light sensitivity
less than BW3.

Colorant		α	β	γ	δ	ω
Estimated luminous flux for each instrument as lux (in millions)		16.5	4.8	6.3	7.1	9.5
Rose Malmaison (New Formulation), Winsor & Newton Designers Gouache	ΔE 76	BW3	BW2	BW2.5	BW2	
	ΔE 94	BW2.5	BW1.5	BW2	BW2	BW2
	ΔE 00	BW2.5	BW1	BW1.5	BW2	
Weber: Emerald Green (Pastel)	ΔE 76	<BW3	BW3	<BW3	BW3	
	ΔE 94	<BW3	<BW3	<BW3	BW3	<BW3
	ΔE 00	<BW3	<BW3	<BW3	BW3	
Le Franc: Garance Cramoisie (Pastel)	ΔE 76	BW3	BW2.5	BW3	BW2.5	
	ΔE 94	BW3	BW2.5	BW2.5	BW2.5	BW2.5
	ΔE 00	BW3	BW2.5	BW2.5	BW2.5	
Mengs Blue (Pastel)	ΔE 76	>BW1	BW1	BW1	BW1	
	ΔE 94	>BW1	BW1	BW1	BW1	BW1
	ΔE 00	>BW1	BW1	BW1	>BW1	
AGFA: Primulin1 @1% (Dye)	ΔE 76	<BW3	BW2.5	BW2.5	BW2.5	
	ΔE 94	BW3	BW3	BW3	BW2.5	BW2.5
	ΔE 00	BW3	BW2.5	BW3	BW2.5	
AGFA: Primulin 1 @5% (Dye)	ΔE 76	BW2.5	BW2	BW2.5	BW2	
	ΔE 94	BW2.5	BW2	BW3	BW2	BW2.5
	ΔE 00	BW2.5	BW1.5	BW3	BW1.5	
AGFA: Zambesi RED B @ 2.5% (Dye)	ΔE 76	BW2.5	BW2.5	BW1.5	BW1.5	
	ΔE 94	BW2.5	BW2.5	BW2.5	BW2.5	BW2.5
	ΔE 00	BW2.5	BW2.5	BW2.5	BW2.5	
Rose Bengal, Winsor & Newton Designers Gouache	ΔE 76	>BW1	>>BW1	>>BW1	>>BW1	
	ΔE 94	BW1	>BW1	>BW1	BW1.5	>BW1
	ΔE 00	BW1	BW1		>>BW1	
Alizarin Crimson, Winsor & Newton Watercolors	ΔE 76	≤BW4	BW3	<BW3	BW3	
	ΔE 94	≤BW3		< BW3	BW3	<BW3
	ΔE 00	≤BW4	<BW3 BW3	BW3	BW3	
Black Construction Paper (Unfaded)	ΔE 76	BW1	BW2	BW2	BW1	
	ΔE 94	>BW1	BW1	BW1	>BW1	BW1
	ΔE 00	>BW1	>BW1	>BW1	>BW1	
Black Construction Paper (Faded)	ΔE 76	BW2.5	BW2	BW2	BW2.5	
	ΔE 94	BW1	BW1	BW1	BW1	BW1
	ΔE 00	BW1	BW1	>BW1	BW1	
Purple Construction Paper (Unfaded)	ΔE 76	>BW1	>>BW1	>>BW1	>BW1	
	ΔE 94	>>BW1	>>BW1	>>BW1	>>BW1	>>BW1
	ΔE 00	>BW1	>>BW1	>>BW1	>>BW1	

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Purple Construction Paper (faded)	ΔE 76	BW2.5	BW1	BW2	BW2.5	BW1.5
	ΔE 94	BW1.5	BW1	BW1	BW2	
	ΔE 00	BW1	BW1	>BW1	BW1.5	
Wild Rose, Ph Martin's Watercolors	ΔE 76	>>BW1	BW1	BW1.5	>>BW1	>BW1
	ΔE 94	>>BW1	BW1	BW1.5	>BW1	
	ΔE 00	>>BW1	BW1	BW1	>BW1	
GIEGY: Acid Green (dye)	ΔE 76	BW2.5	BW2.5	BW2.5	BW2	BW2.5
	ΔE 94	BW2.5	BW2.5	BW2.5	BW2	
	ΔE 00	BW2	BW2	BW2	BW2.5	
GIEGY: Erio Cyanine A @0.5% (dye)	ΔE 76	<BW3	BW2.5	BW2.5	BW2.5	BW2.5
	ΔE 94	BW2.5	BW2.5	BW2.5	BW2	
	ΔE 00	BW2.5	BW2.5	BW2	BW2.5	
GIEGY: Violet Diphenyl TS @0.5% (dye)	ΔE 76	BW3	BW3	BW3	BW3	BW2.5
	ΔE 94	BW3	BW2.5	BW2.5	BW2.5	
	ΔE 00	BW3	BW2	BW2	BW2.5	

4.2 AGREEMENT BETWEEN INSTRUMENTS ISO BLUE WOOL ASSIGNMENTS

Figure 6 presents the agreement between all five instruments when DE94 was used to assign ISO blue wool equivalency to the seventeen test materials. Four of the seventeen materials were assigned identical sensitivities. Eight agreed to within ½ of a blue wool step making 71% of the materials achieving ½ step agreement or better. Four samples were within 1 full step and one sample ranged over 1 ½ steps. No material was misclassified as insensitive. In addition thirteen of seventeen samples agreed over three of the five instruments perfectly, and eight agreed over four of five.
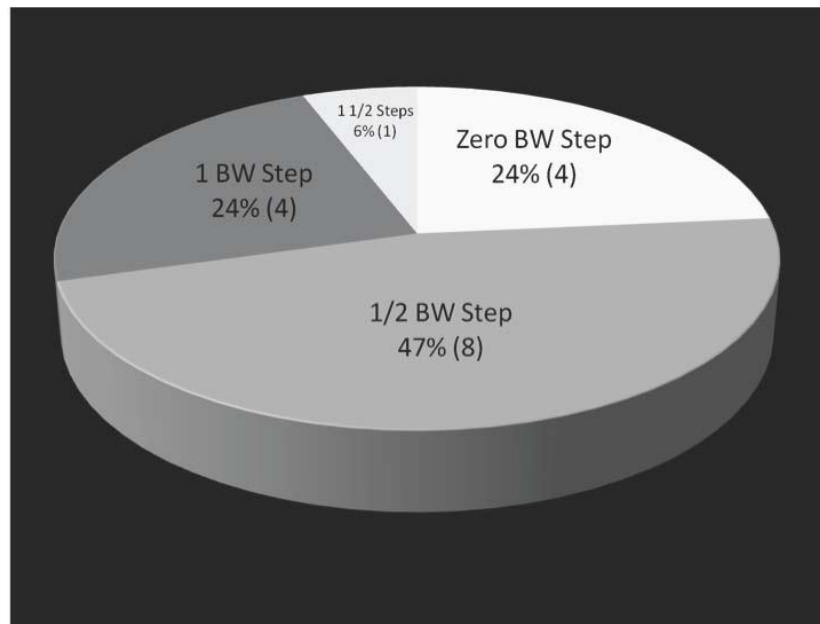

Figure 6. Agreement between instruments for assessments based upon the DE94 color difference equation.

While we recommend DE94 for making light sensitivity assessments, either DE94 or DE2000 can be used to examine the changes in colorimetry because of their similarity. Figure 7 shows how much color change was produced after 30 minutes for the most sensitive materials tested and figure 8 for the remainder. Both of these use DE2000 for the y-axis. In general, the microfader with the highest flux produced the most extreme color changes and the one with the lowest flux produced the smallest color changes. Figure 7 shows this very well. But not all materials behaved in this manner. Figure 8 shows that for the three Agfa dyes on cotton the more powerful Alpha instrument produced a lower color change than the Delta instrument which was significantly less powerful. This cannot be attributed simply to Delta's more efficient lensless probe because even the Beta instrument which had Whitmore original probe design produced larger color changes than the achromat-equipped probe of Alpha. At this point the reason for this apparently anomalous behavior is a mystery. Nevertheless, the degree of agreement with assessments based on DE94 given these large differences in luminous flux suggests that the technique is robust and similarly captures the behavior of these colorant systems with all the modifications made here to Whitmore's original design. The level of disparity that remains is probably consistent with the types of uncertainties attendant with risk assessment techniques in general.
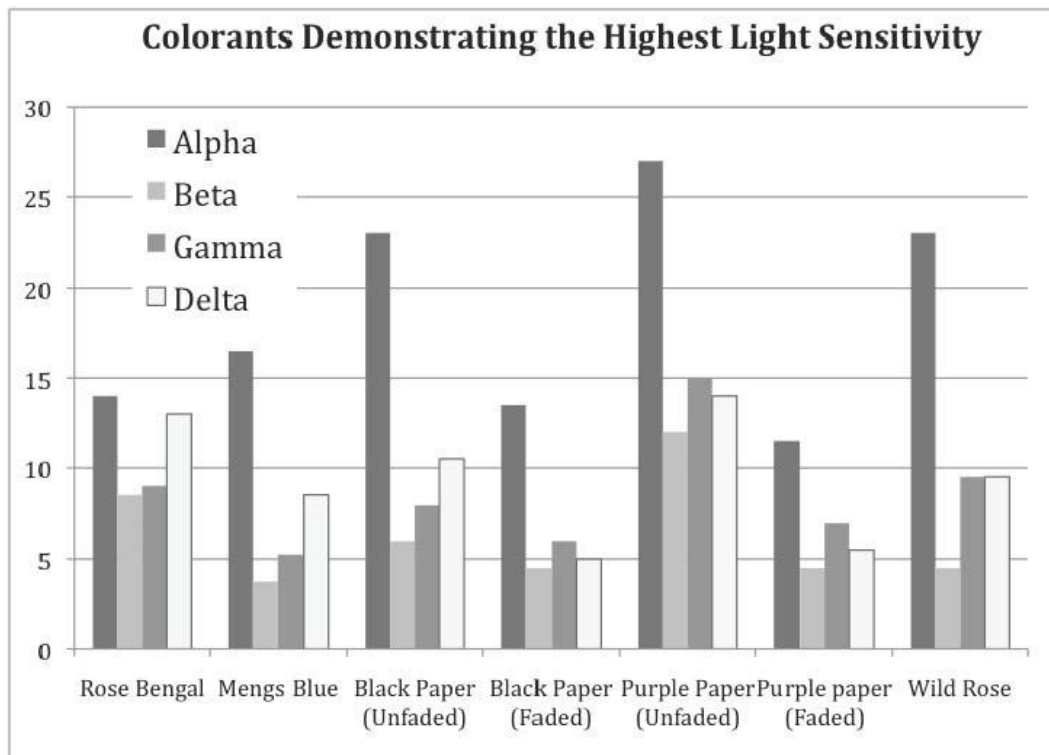

Figure 7. Plot of DE2000 after 30 minutes for seven of the most light sensitive colorants tested. Alpha represented 16.5 million lux exposures. Beta produced 4.8 million lux. Gamma produced 6.3 million lux. And Delta produced 7.1 million lux.
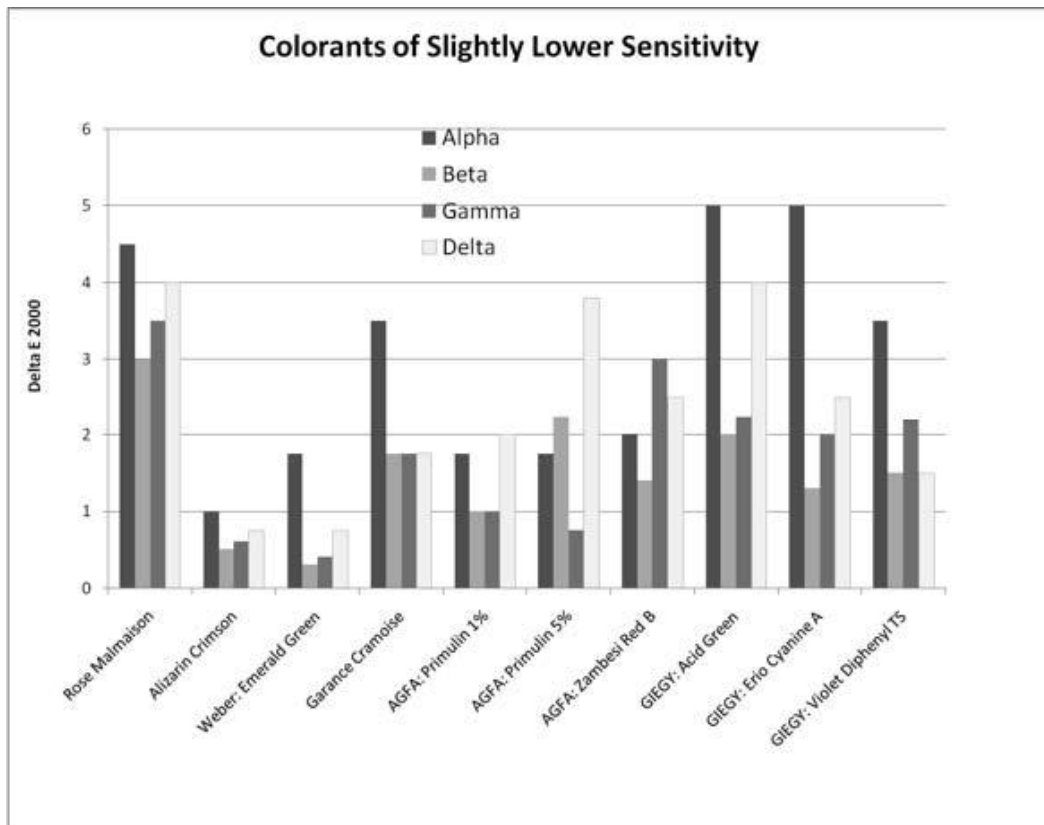
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Figure 8. Plot of DE2000 for the materials with lower sensitivity.

5. CONCLUSIONS

After a meeting of users of the microfading technique in April 2009 at the ICN we became apprehensive at the range of experimental freedom users were taking in modifying and creating whole new designs for these tools. Since the majority of instruments were built upon the core design of Whitmore the decision was made to duplicate the innovations in our lab and test their reliability on a common set of materials. In the absence of a real round robin series of testing with a dozen institutions participating, we set out to test their equipment ourselves. Five instruments were created and assessments made on seventeen materials, running 4 replicates for each. Replicates for the blue wools were run frequently over the period of the study. Testing all three color difference equations it was determined that the any one of the equations, if used consistently, would provide reliable results but that DE94 had certain advantages justifying its recommendation.

Four of the seventeen materials were assigned identical sensitivities by all five instruments. Eight agreed to within ½ of a blue wool step making 71% of the materials being assigned a ½ step agreement or better. Four samples were within 1 full step and one sample ranged over 1 ½ steps. No material was misclassified as insensitive, nor were any of the known sensitive materials misclassified as not. In addition thirteen of seventeen samples agreed over three of the five instruments perfectly, and eight agreed over four of five.

As a result we feel that all the microfaders now being operated in figure 1 and table 4 should be able to engage in comparisons between laboratories with reasonable consistency and that databases of light-sensitive materials can feasibly be built with different contributors. The next step is to clarify the comparability of these instruments as operated by different individuals. There was no effort to compile the protocols that different individuals and institutions employ or evaluate the assumptions they use in making their own ISO blue wool assessments. These steps must wait for a later time when a true round robin cycle of testing can be accomplished.

ACKNOWLEDGEMENTS

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PROTECTING THE MOST IMPORTANT, MOST EXHIBITED
AND MOST FUGITIVE MUSEUM OBJECTS FROM LIGHT-FADING

BRUCE FORD AND NICOLA SMITH

ABSTRACT – In late 2007 the authors were asked to review the National Museum of Australia's lighting guidelines because the Conservation and Finance Managers had serious concerns about the cost of light-driven object replacements. Two underlying factors, both potentially able to be addressed, were found to be responsible for the high replacement rate. The first was a lack of reliable fading-rate data for much of the collection, leading both to conservative and inflexible display restrictions and probable over-exposure of the most fugitive colorants, which could not be reliably identified. The second was an implicit assumption that, for the purposes of setting display periods, all objects are equally likely to be displayed, and therefore equally exposed to light over time.

The Museum subsequently acquired an Oriel® Fading Test System by Spectra Physics that has proven to be a highly cost effective means of distinguishing materials at real risk of unacceptable fading from those for which exhibition times may safely be extended. The micro-fading results inform a lighting regimen in which objects of high significance to the museum, and therefore likely to be in regular demand for exhibition, are given the same or less exposure per exhibition period than before, and the majority of less-used items allowed more exposure when exhibited. This dual approach allows the museum to concentrate its resources on the most important, most displayed, most fugitive – and therefore most vulnerable – colorants in the collection.

PROTECCIÓN DE LOS OBJETOS DE MUSEO MÁS IMPORTANTES, MÁS EXHIBIDOS Y MÁS FUGACES DE LA DECOLORACIÓN POR LA LUZ: RESUMEN – A fines de 2007 se pidió a los autores que revisen las normas de iluminación del Museo Nacional de Australia debido a que los Gerentes de Conservación y Finanzas tenían serias preocupaciones con respecto al costo de reemplazos de objetos afectados por luz. Se determinaron dos factores subyacentes, ambos potencialmente tratables, como los responsables del alto índice de reemplazo. El primero era la falta de datos confiables sobre el índice de decoloración para gran parte de la colección, lo que causaba restricciones de conservación e inflexibilidad de la muestra y probable exposición excesiva de los colorantes más fugaces, que no podían ser confiablemente identificados. El segundo era una presunción implícita de que, a los efectos de establecer periodos de exhibición, todos los objetos se exhiben de igual manera, y por lo tanto se exponen de igual manera a la

luz con el paso del tiempo.

El Museo posteriormente adquirió un Sistema de Prueba de Decoloración Oriel® de Spectra Physics que demostró ser un medio sumamente rentable para distinguir materiales en riesgo real de decoloración inaceptable de aquellos para los cuales se podría prolongar con seguridad los tiempos de exhibición. Los resultados de la microdecoloración advierten de un régimen de iluminación en el cual los objetos de mayor importancia para el museo, y que tienden a tener una demanda regular de exhibición, reciben la misma exposición o menos por cada periodo de exhibición que antes, y la mayoría de los artículos menos utilizados reciben mayor exposición al ser exhibidos. Este doble enfoque hace que el museo concentre sus recursos en los colorantes más importantes, más exhibidos, más fugaces; y por lo tanto, más vulnerables de la colección.

1. INTRODUCTION

The National Museum of Australia (NMA), which first opened to the public in 2001, is a social history museum tasked with representing the continent's long human occupation. At present this is achieved through a series of 'permanent' exhibitions on the themes of Land, People and Nation that are refurbished every ten years, and through temporary exhibitions, usually of less than one year's duration, which examine particular social and historical topics. The museum has a large and varied textile and natural fibre collection covering traditional and modern indigenous Australian and Torres Strait Island items, and non-indigenous textiles from the early colonial period of the late 18th century until the present day. These include colorants predating the first synthetic dyes of the mid-19th century, and a range of synthetic and natural dyes employed in hand and factory fabric dyeing and printing since that period.

Published fading rate data for these textiles, and a vast range of other colored objects in the collection, is sketchy at best; nevertheless light-exposure decisions need to be made on the basis of conservators' experience and the best evidence available. In 2000 the Conservation Department adopted a slightly modified form of the exhibition lighting guidelines (Tait et al 2000) developed at the Victoria and Albert Museum (V&A) in the late 1990s (Derbyshire & Ashley-Smith 1999, Ashley-Smith et al. 2002), which built on earlier work by Colby (1992). A similar approach was subsequently taken by the International Commission on Illumination in their technical report on the control of damage to museum objects by optical radiation (CIE 2004). In the NMA's implementation of the V&A guidelines objects of (estimated

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or assumed) lightfastness ranging from the most unstable down to ISO Blue Wool 4 (BW4) equivalent were labelled "sensitive", and with their exposure based on an average stability of BW2, limited to two years display at 50 lux. More stable material classified "durable" (BW5-7) and "permanent" (BW8) could withstand proportionally greater or indefinite cumulative exposures. Higher light levels could be traded off against shorter display times providing cumulative exposures were tracked over time.

Like the Netherlands National Museum of Ethnology, however, the Museum found that in practice "[the] amount of work that such an extensive replacement programme would entail … [was] … a major problem" (Reuss et al. 2005, 693). At an estimated average cost of $1000 per light-driven changeover, including curatorial time locating and interpreting suitable replacements, registration activities, conservation, de-installation, re-installation, relighting and so on, application of the guideline was costing the NMA hundreds of thousands of dollars a year without a clear commensurate benefit. A way was needed to reduce costs and, perhaps even more importantly over the long term, address concerns that the BW2 average exposure for the 'sensitive' range over-exposed (by definition) the most fugitive materials. Another aim was to introduce more flexibility in lighting levels, including an option to exceed the 50 lux limit that in practice applied to most colored materials, and which for reasons outlined by Michalski (1997) are often too low for adequate viewing. These include low contrast and fine detail, viewing distance, darker objects and the inevitable decline in visual acuity that accompanies age related macular degeneration.

2. REVIEW OF LIGHTING GUIDELINES

When the Museum's past practices and experiences as well as a range of other museums' lighting policies were reviewed, two factors emerged as contributing most to the high cost of protecting the collection from excessive light damage. Each problem related to a different aspect of a general inability or unwillingness to impose exposure restrictions selectively rather than across the board.

The first and most obvious reason was gross uncertainty about the specific or even general lightfastness of the majority of the collection, which saw nearly all colored textiles classified as "sensitive" as a matter of precaution. With relatively few exceptions relevant light fastness data in the literature is limited to generalisations based on accelerated studies of newly prepared surrogate samples of mostly European historical interest. In practice it is rarely possible or economically feasible for conservators to routinely identify dyes and pigments. Even if this were not the case a colorant's identity does not determine crucial aspects of its light-fastness. Just as important are the extent to which fading has already occurred, dye preparation and application,

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substrate and other constituents, mordant type and concentration, depth of shade, pollutants and contaminants, washing, and the botanical origin and growing conditions of natural dyes.

Ideally, exposures would be based on monitoring the color change of individual objects under museum lighting conditions, however while this is sometimes feasible (Ford 1992), it is extremely time consuming and difficult or impossible in many cases for technical reasons. Accepting that accelerated techniques are necessary, Whitmore's (1999) microfade tester appeared to be the most practical way of bridging the information gap because it offered routine, rapid, and non-destructive access to object specific fading rate data.

The second factor – which none of the published guidelines addressed despite being based on hypothetical display lifetimes of several hundred years   –   is the underlying assumption (for the purpose of calculating exposure limits) that all objects are equally likely to be displayed, and therefore equally at risk of fading over time. In reality only a small proportion of the potentially light-sensitive objects in the Museum's collection are in such constant demand. From this it follows that equally restricting access to all objects irrespective of their likely display frequency is a costly overreaction, and if there were a way to estimate an object's "future display history" the less likely-to-be displayed part of the collection (the majority) might be left on exhibition longer without exceeding the cumulative color change targets in the existing guidelines. This idea had the merit of potentially reducing the cost of light driven replacements even without better fading rate data, although it would do nothing to identify and safeguard the most fugitive colorants.

Garry Thomson (1986, 33), who is most often cited as the authority for limiting the display of nearly all potentially fugitive materials to short periods at very low light levels, had actually addressed both of these issues when he recommended 50 lux 'for all very valuable material[s] ...that are especially sensitive to light'. He succinctly summarises the case for selectively restricting display, however the qualifier "for all very valuable material' – referring to objects for which there is most exhibition demand and for which the loss of value is potentially greatest – appears to have been largely ignored as conservators rushed to conform to unofficial international "standards" and researchers focused their attention on fading rates.

3. USING SIGNIFICANCE ASSESSMENTS TO REDUCE LIGHT-DRIVEN OBJECT REPLACEMENTS

Identifying and ranking significance in a consistent and meaningful way for museums has been systematically addressed by the Collection Council of Australia (CCA), whose   significance assessment methodology (Russell & Winkworth 2009) is based on the 1979 ICOMOS Australia

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'Burra Charter" (ICOMOS 1999) which has been used for over 30 years to prioritise and guide
conservation decisions for cultural sites. Notwithstanding that some conservators were trained to
believe it is unethical to base conservation decisions on value judgements (the so-called
Rembrandt Rule), there is nothing new or particularly controversial about doing so, in fact it is
impractical not to. The Burra Charter has evolved into an approach to heritage management
called "Values Based Management (VBM)" (UNESCO 2010) and there is a growing literature on the
subject for museums, particularly in relation to risk management (Michalski 2004, Waller 2003)
where significance is used to measure potential loss. It is endorsed by AIC's sister organisation in
Australia, the AICCM, whose code of ethics states (AICCM 2002, 4):

> [i]t is recognized that the significance of cultural material may have a bearing on
> conservation decisions. Accordingly ... the AICCM Member shall ensure that
> cultural material in her/his care receives levels of conservation appropriate to its
> significance and available resources.

The CCA publication breaks significance down into four overarching socio-cultural categories: historic,
aesthetic, research and social or spiritual. Objects or collections are ranked in relation to one another
within these categories according to comparative criteria: provenance, representativeness, rarity,
condition and, importantly for a social history museum like the NMA, interpretative potential.

A statistical analysis of past exhibitions revealed that it was necessary only to sort objects into two
categories, 'high use' and 'the rest', to significantly reduce light-driven changeovers by allowing those in
the second category to remain on display longer. An exposure guideline was developed (table1) in which
objects not considered likely to be in continuous demand for exhibition would be 'downgraded' to the
next most stable category where their total color change over time remains much the same or less than
their equivalent sensitivity 'high use' counterparts. An object, for example, that would be limited to 2
years display on the basis of its assessed blue wool rating (4 replacements/permanent exhibition
assuming it is replaced with similar objects), could be displayed for 5 years (1 replacement) if it were not
in the "high use" group – a saving of 75% in replacement costs. In developing this guideline the V&A's
color change limit of 1 Just Noticeable Fade (JNF)/50 years was retained, while recognising that, for
various reasons, counting JNF's may not be realistic (Ford & Smith 2009). The specific display intervals
were kept in place because they were already embedded in forward work schedules incorporating 2 and
5 year changeovers.

The two tiered approach in table 1will be trialled when the administrative and organisational

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arrangements, such as how significance is documented, recorded and communicated, and how frequently significance assessments should be repeated to account for changing circumstances, have been finalised. In the meantime display durations are set as if all objects are in the high significance/high use category and exposure is determined purely on the basis of microfading results. The strong intention is to avoid applying the criteria mechanically or inflexibly because fading rates and light levels are only part of the decision making process; for example the handwriting on an important historic document was determined to be relatively lightfast (BW4-3) according to microfade testing, but only because it was already very faded. With this in mind the lighting recommendation was much more conservative than the fading rate data would normally indicate because the contrast between the yellowing ink and the parchment was already very low and would likely decline seriously with any additional change.

Eventually a combination of pre-selection using significance and more valid generalisations based on previous testing should cut the proportion of objects tested, with the caveat that it is not unusual for superficially similar materials to test very differently. For this reason all high significance objects will be fade-tested individually unless there are very good grounds for not doing so.

Table 1.Significance based lighting framework, where BW = ISO Blue Wool Fading Standard, based on a color change target of less than 1 Just Noticeable Fade/50 years.

ISO (BW#)	< about BW2	about BW2 −3	about BW3 −4	> about BW4
	about 50 lux	50-100 lux*	50-150 lux*	100 -250 lux*
Exposure of high significance (high use) objects	individually decided	2 years/decade	5 years/decade	life of exhibition
Exposure of average significance (lower use) objects	Individually decided	5 years/decade	life of exhibition max 10 years	life of exhibition max 10 years

*as low as possible consistent with good display.

4. MICROFADING

The V&A's exposure recommendations for colorants less stable than BW4 are based on an average fading rate of BW2. This 'underexposes' the more stable colorants according to the 1JNF/50 year criterion, imposing unnecessary and costly access restrictions, and risks over-exposing colorants whose lightfastness is less than BW2. These are the very dyes and pigments that will suffer significant damage over a relatively short period of display, even under museum conditions. The logical way to contain costs (if one is reasonably sure of relative fading rates) is to allow those at the lower end of the 'sensitive' range greater exposure than the more fugitive ones, where the increase is justified by the twofold decrease in stability for each numerical step up the ISO Blue Wool increments. This approach was

adopted by the Netherlands National Museum of Ethnology, whose conservators subdivided the 'sensitive' range into 'sensitive 1' (BW1 or worse), 'sensitive 2' (BW2-3) and 'sensitive 3" (BW3-4), with an additional 'vulnerable' category containing 'sensitive 1' objects that are also pristine (Brokerhof et al. 2008). Incidentally, the last category is actually a significance judgment based on 'condition' and probably 'rarity' as well, since pristine-ness is not a common characteristic of historic materials of low lightfastness. We believed that in practice, however, sorting objects in the Museum's very diverse collection into such narrowly defined categories would often amount to little more than guesswork.
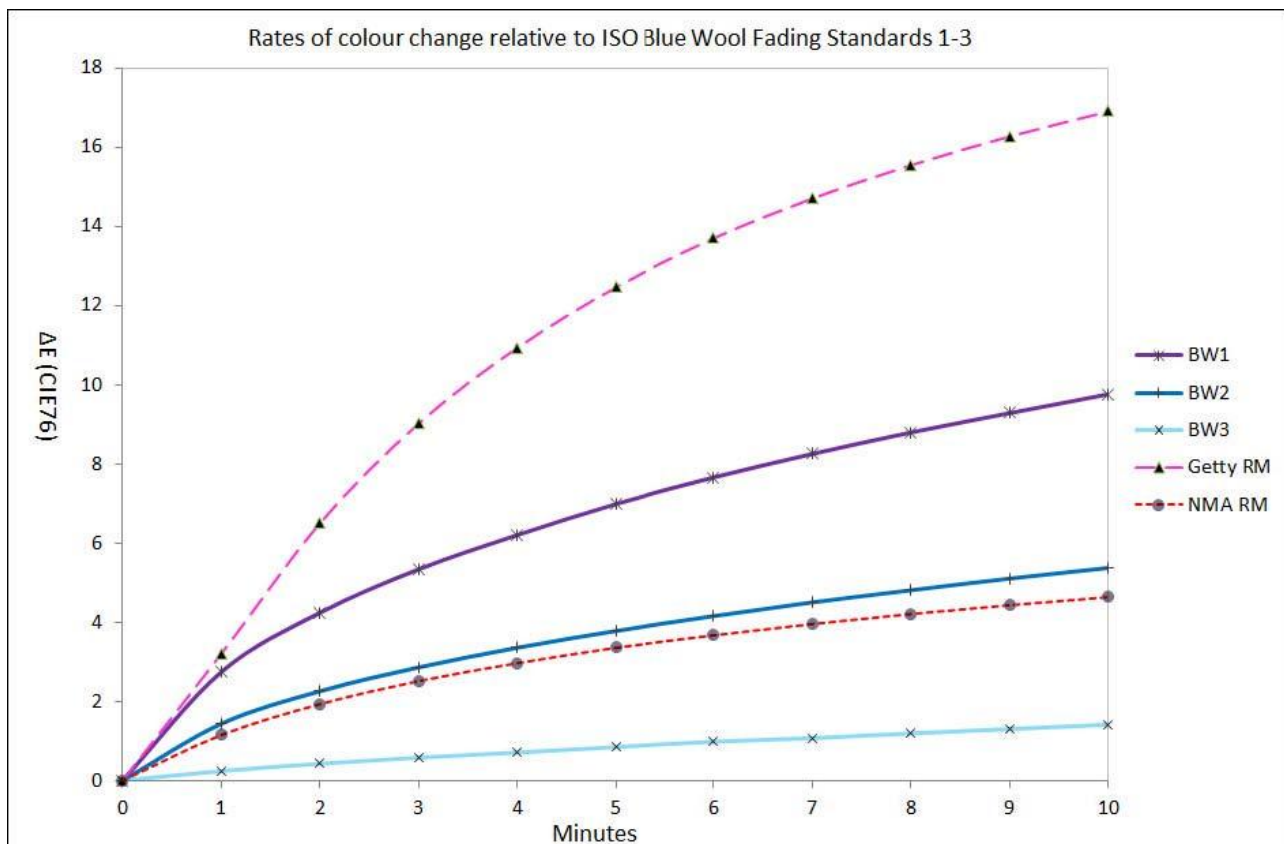

Figure 1. Fading rate curves, separate tubes of W&N Rose Malmaison purchased in the USA (Getty) and Australia (NMA).

In 2008 the Museum acquired a Newport Oriel® Micro Fade Tester and since then accelerated lightfastness measurements have been made on hundreds of objects representing well over 1000 colorants. Direct measurement approaches like Whitmore's (1999), and also Pretzel's (2000, 2008) studies of the Bullerswood and Ardabil Carpets, cut through the maze of unknowns (and unknowables) by rapidly and non-destructively quantifying – to the extent possible with accelerated ageing – the

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lightfastness of the item intended for display. It is completely unnecessary to know the identity of colorants and substrates or specific dyeing processes and subsequent history; although where this kind of information is available it provides a fascinating physical and chemical context for micro-fading results.

Conversely there is good reason to believe that with the benefit of accumulated data on relatively well characterised colorant and substrate systems, micro-fading will complement existing analytical methods on the basis of reflectance spectra and spectral and colorimetric change under test conditions. A glimpse of this potential is provided in figures 1 and 2, where two very similar paints are clearly distinguishable by their fading rates and colorimetric change. The spectral data (not shown) provides additional information.
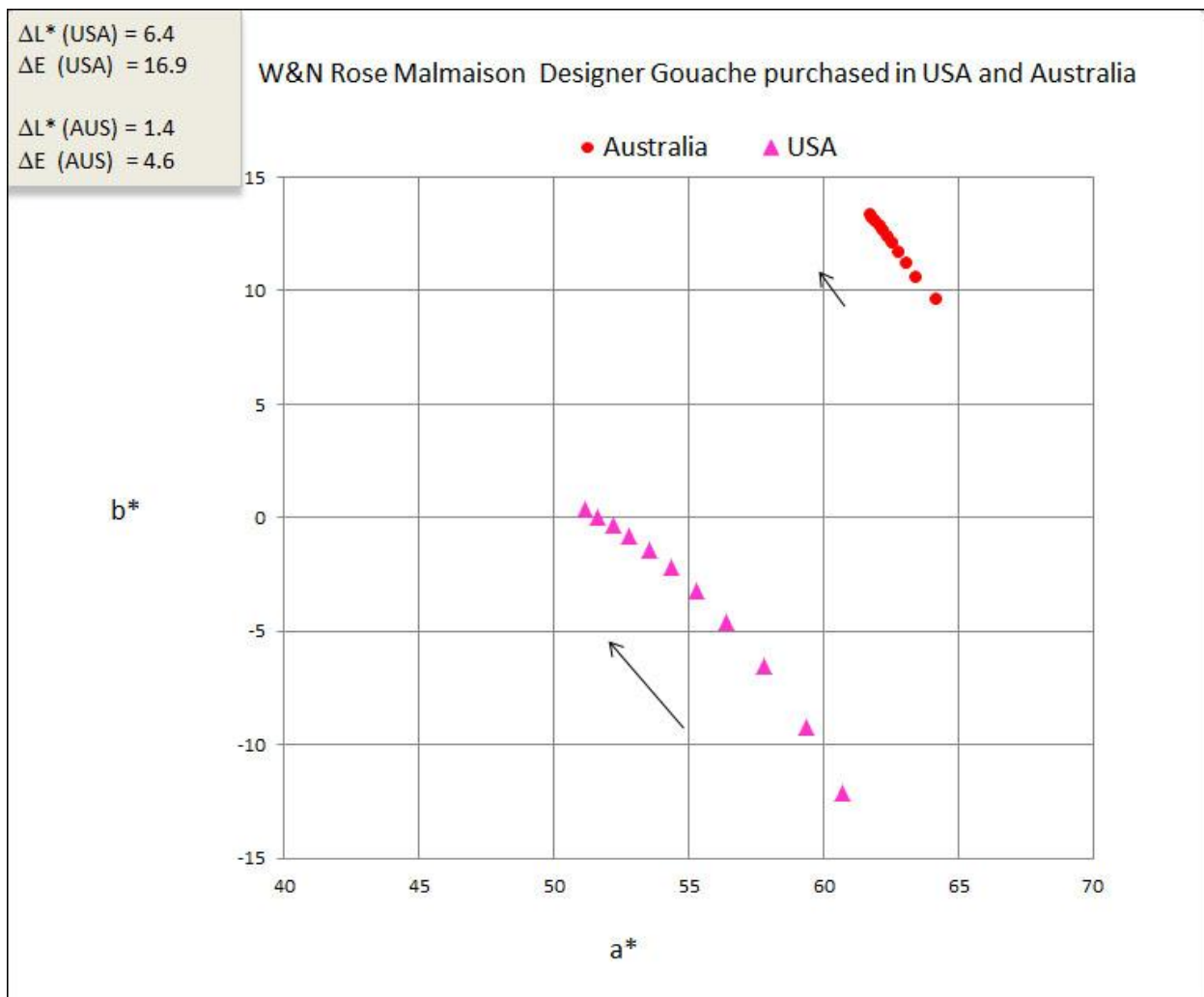

Figure 2. CIEDE76 a* b* plot, W&N Rose Malmaison USA and NMA. Clearly shows the two paints are different.

One of the difficulties with using the existing tables is that the assumed stability depends on qualifiers such as "most" (furs), "cheap" (synthetic colorants) "good quality" (acrylics, paper) or "carbon" (inks), however even leaving aside prior exposure and other factors that profoundly affect fading rates, how is the exhibition conservator to tell?   In fact, one of the most consistent lessons from microfade testing is that lightfastness is often unpredictable. Winsor and Newton's 'Rose Malmaison' designers' gouache is a good example. Two different tubes of this rhodamine based paint, which has a manufacturer's light fastness "c" rating (poor), were microfade tested by the GCI and the NMA. Its lightfastness had also been determined by microfading and published by Whitmore (1999); the labeling of the two tubes (one bought in the USA and the other Australia) were identical; both were painted out on filter paper; and neither had received prior exposure to light. Furthermore according to Winsor and Newton there had been no changes in formulation. This is the best possible scenario for using V&A or CIE type heuristic guidelines, however the paint from each of the tubes reproducibly faded at very different rates and occupied different positions on the a* b* plane of the CIE76 L*a*b* color space (figs. 1 & 2). Exposures based on the NMA's tube at BW2 would seriously overexpose paint from the GCI's tube, which was much less stable than BW1.
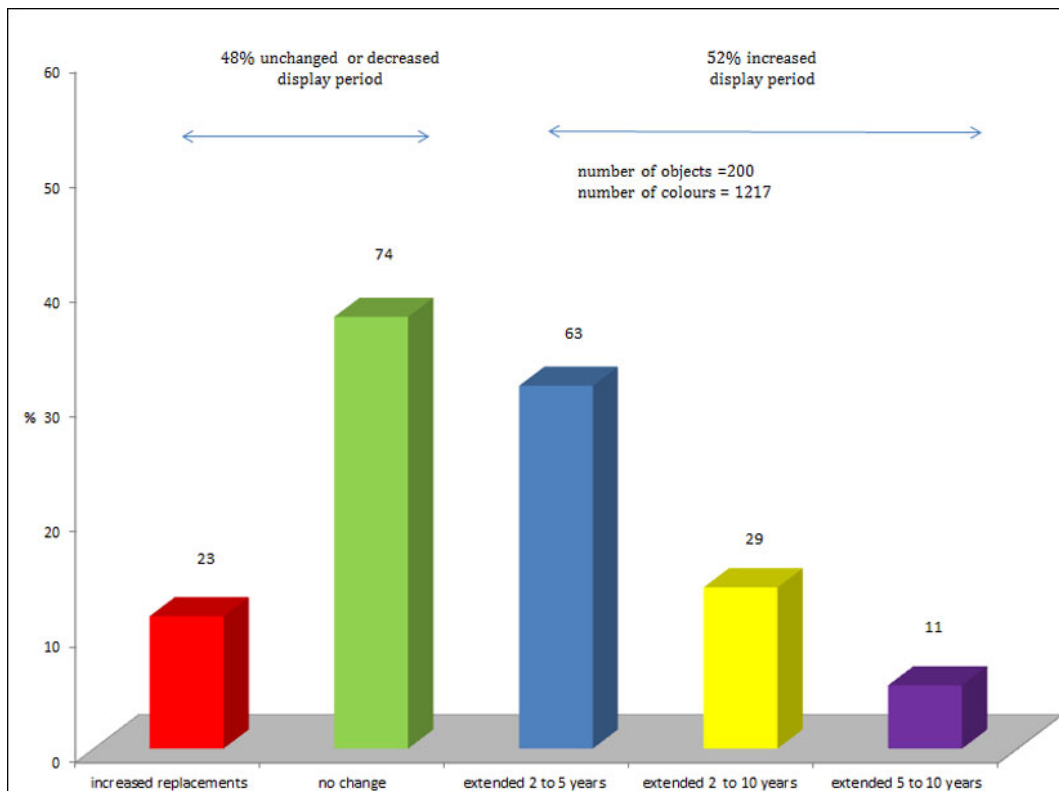

Figure 3. Changes to recommended exhibition duration based on microfade testing of 200 objects selected for exhibitions during 2009-10.

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Shortly after the acquisition of the O-MFT routine microfade testing began on most colored objects destined for 'permanent' exhibition, ranking their lightfastness against the ISO Blue Wool fading standards 1-4. In most cases, the exhibitions in question were already in place; however changes to light-driven replacement rates for 200 objects in figure 3 show that if microfade testing had been carried out from the outset, 70-80% of replacements would have been avoided over the exhibitions' (10 year) display cycle. At $1000/replacement, this would represent a saving in the order of $700,000 to $800,000 per year to the museum. As it is for the 200 objects tested, more than 800 changeovers have been saved over the remaining lives of the exhibitions, largely by extending the display of objects in the two year category out to five. According to these figures the benefit of microfading is at least an order of magnitude greater than the cost of testing.

As expected, a significant minority of objects (12%), some of them very important, would certainly have been over-exposed if they were displayed for 2 years at 50 lux according to the criteria underpinning the old heuristic guidelines. While many of them were predictable (daylight fluorescent colors for instance) others were not: for example black inks on good quality paper and even artists' acrylic paints which under the old NMA guidelines (Tait et al 2000) were all considered "durable" and eligible for permanent display at 150 lux.

5. CONCLUSION

Lighting decisions are often a source of tension in museums where conservators have been cast – or cast themselves – in the unfortunate role of "lighting police" (Michalski 1990, 586). It is uncomfortable to enforce rules based on inadequate data, especially when it has such a serious impact on access, other people's work, and operating costs. Collection care is increasingly defined as a process of "making well informed decisions to prioritize and allocate resources to optimize the value of our collections" (Brokerhoff 2006, 1) and in the context of light exposure, museums badly need the better data microfading affords. A significance filter will help to identify objects in high demand and therefore more exposed to light over time, and also more broadly to define the values which conservation aims to protect, whether they are physical integrity, historical and spiritual associations, information content or pristineness. In this sense the lighting project is a useful test case for the wider introduction of risk management principles based on minimizing loss of value(s) (Waller 2003). Even in relation to color alone there are factors other than light whose effects need to be weighed up against exposure related damage, for example thermal yellowing, or physical changes to feathers where color is partly or wholly structural in nature.

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The Museum's old lighting guidelines resulted in well-intentioned, but unnecessary over-protection of about half of all objects in long-term displays, and over-exposure of a vulnerable minority that are not easy to predict. Their application seriously limited access to many objects and spread the available resources over the whole collection instead of concentrating on the objects at greatest risk. A greater than necessary number of sometimes fragile objects were subjected to physical interventions and handling, and unreasonably low exhibition light levels were generally adopted. While microfading is a relatively new technique, and there will always be uncertainty about the correlation between accelerated and museum fading in any particular case, there is little doubt that at worst it reliably flags very fugitive colorants. It is the best available scientific risk management tool to selectively limit light damage at this time, and it has given the NMA the confidence to display its collection to best advantage now, and to keep it for the benefit of visitors and scholars well into the future.

ACKNOWLEDGEMENTS

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DEVELOPMENT OF A MICROFADING TESTER FOR LIGHT EXPOSURES

INCLUDING NEAR-ULTRAVIOLET WAVELENGTHS

CHONG TAO AND PAUL M. WHITMORE

ABSTRACT– A new microfading tester (MFT) was developed for light exposures containing near UV wavelengths, namely 300-700nm. The required light (solar simulation) was generated from proper filtration and sampling of light from a xenon lamp. The chromatic aberrations of the simple focusing lenses were studied with microscope imaging and utilized to create the desired focus across the entire wavelength range. The effect of including the UV radiation on the fading of Blue Wools and rose madder, a known UV-sensitive pigment, was studied. A protocol is proposed for using the conventional MFT with only slight modifications to include the UV wavelengths.

DESARROLLO DE UN TESTER DE MICRODECOLORACIÓN PARA EXPOSICIONES A LA LUZ INCLUYENDO LA LONGITUD DE ONDA ULTRAVIOLETA CERCANA. RESUMEN – Se desarrolló un nuevo tester de microdecoloración (MFT) para las exposiciones a la luz con longitudes de onda ultravioleta cercana, es decir 300-700nm. La luz necesaria (simulación solar) se generó a partir de una debida filtración y muestra de luz de una lámpara de xenón. Se estudiaron las aberraciones cromáticas de los lentes de enfoque simple con imágenes de microscopio y se utilizaron para crear el enfoque deseado a lo largo de todo el rango de la longitud de onda. Se estudió el efecto de incluir la radiación UV en la decoloración de Blue Wools y el rojo carmesí, un reconocido pigmento sensible a la luz UV. Se propone un protocolo para utilizar el MFT convencional con leves modificaciones solamente para incluir las longitudes de onda UV.

1. INTRODUCTION

The microfading tester (MFT) is a tool used to characterize the light sensitivity of colored materials encountered in cultural property by performing tiny, sensitive fading tests directly on those objects (Whitmore et al. 1999). Originally aimed at identifying fugitive colorants (ISO Blue Wool 1 or 2 lightfastness grade) exhibited in indoor environments that are free of ultraviolet radiation, the MFT was designed to deliver high intensities of visible light to the test spot. While the overall performance of the original instrument design has been shown to be reasonably well correlated to other accelerated light

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exposures, the device has since been modified by various users to address some known shortcomings of the simple optical system, such as chromatic aberrations that slightly distort the wavelength spectrum delivered to the test area. Those improvements have generally led to very small changes in the instrument performance.

Over time users have begun to explore whether the MFT can be used to answer other questions about light sensitivity of artifact materials. Of particular interest is the characterization of the fading of more stable colorants (ISO Blue Wool 3 and greater), which tend to fade primarily from exposure to ultraviolet wavelengths. The original MFT design allows for some delivery of ultraviolet light simply by removing a UV-blocking filter. However, the relative intensity of ultraviolet (UV) wavelengths is not easily controlled, for it is sensitive to the focusing of the lenses in the device. Modified instruments that have incorporated achromatic lenses may be particularly limited in this regard, since those lenses generally do not transmit UV wavelengths.

In this paper the modification of an MFT to deliver controlled intensities of light from near-UV wavelengths through the visible spectrum is described. A new spectrometer, able to measure both visible wavelengths and the UV region, has been incorporated. Simple lenses are still used in order to keep the cost of the instrument reasonable and to allow straightforward adaptation of current devices. The chromatic aberrations inherent in those lenses have a greater impact on the spectrum of focused light, and thus on the fading results. Techniques to operate the instrument to optimize delivery of the desired wavelength spectrum are explored. The performance of the new instrument to measure the fading of materials having lightfastness of ISO Blue Wool 3 and greater are presented.

2. INSTRUMENT DEVELOPMENT AND TESTING

The new microfading tester was built as a modification of the generic Oriel type, currently available as the kit. To keep the price of the system from becoming formidably high, simple quartz lenses or lens systems that are used in the standard configuration were employed, as most commercial achromatic lenses do not transmit well for wavelength short than 400nm. In order to monitor the whole spectral region from 300-700nm, a new spectrometer (USB silicon PDA spectrometer from Control Development, Inc.) with response between 250-780nm was used. It can be controlled either by the commercial software coming with the spectrometer or by a program written with LabView. Filters used for the new system are described in the following section.

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2.1 LIGHT SOURCE AND FILTERS

In the development of the MFT, the most important factors are effectively delivering the light with the desired spectral power distribution to the test area and effectively focusing the light throughout the spectrum range, to create the high intensities. Chromatic aberrations in the simple lenses will tend to distort that delivered spectral power distribution, as some wavelengths are focused to a higher intensity than others. Since the desired spectral range runs from 300 to 700nm, a xenon arc lamp remained a good choice as the light source. Different filters have been used to deliver the spectral range desired. First, a borosilicate glass filter combined with a 2 in. water filter gave a spectral range of 300~1000nm. The heating at the test area was found to be up to 38oC under ambient conditions, which should not be a problem for most applications. A KG-2 glass filter was also tested, which produced a spectral window between 300nm to 800nm, and according to the specifications it also transmits less than 20% of the lamp output in the infrared region between 1 µm and 2.5 µm. Using this filter alone would generate the desired spectral window and cause only a slight temperature increase in the test area to 36oC under ambient conditions. The only drawback of the KG-2 glass filter is that it can only take 30w/cm2 of illumination. Higher light intensities will damage the filter due to excessive heat. For all the experiments described in this paper, the combined water and borosilicate glass filters were used to generate the spectral power distributions delivered to the samples.

As mentioned in previous section, all the lenses in this modified MFT system are simple quartz lenses, which have slight chromatic aberrations. One can, however, utilize these aberrations, for they allow slight adjustments to tailor the spectral power distribution of the light delivered to the test area. In this MFT system, light from the xenon lamp is collimated with the condenser lens in the lamp housing, then focused by a lens in the optical fiber coupler onto the fiber tip, before being delivered to the illumination lens assembly in the test head. Because of the chromatic aberration in the lens in the optical fiber coupler, the spectral power distribution delivered into the fiber end is slightly altered depending on the position of the fiber end. At any given position of the fiber end, some wavelengths will be more tightly focused and thus more efficiently injected into the fiber. So adjusting the optical fiber position slightly enables the sampling of different portions of the focused light. Shown in figure 1, different spectral power distributions were obtained by adjusting the fiber position relative to the lens in the optical fiber coupler. Since this adjustment is continuous, the spectral power distribution was adjusted to achieve the best match with indoor natural sunlight, or in this case, with another

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commercial xenon exposure cabinet, the Atlas SunTest CPS, that was designed to simulate the solar

spectrum (fig. 2). The light below 400nm accounts for 16% of the total energy. Also shown in figure 2 is

the spectral power distribution of the MFT when it is aligned for its typical use in visible-only tests. The

usual optimization to maximize lumen output (i.e., maximize output at around 550nm) causes reduced

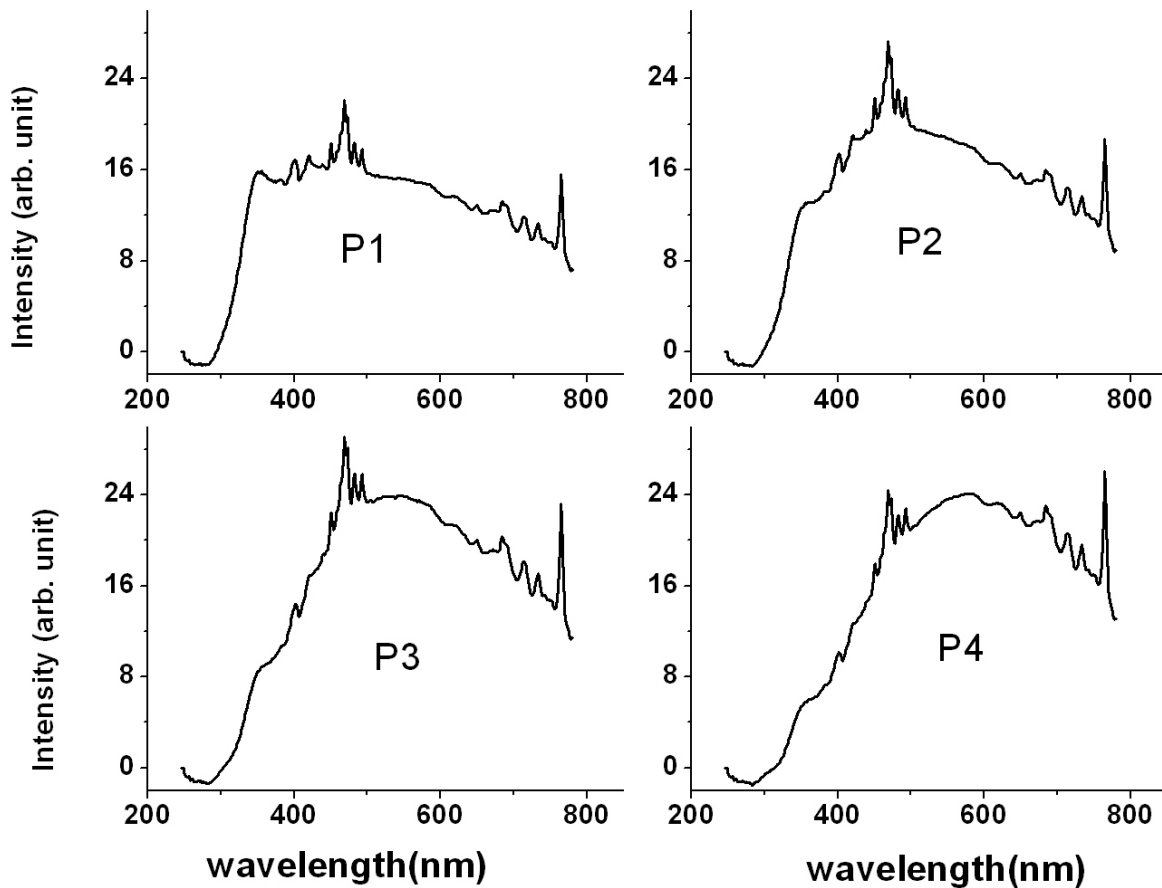intensities to be delivered at the short wavelengths.

Figure 1. Spectral power distributions of the Xe light exiting the optical fiber for 4 different optical fiber
coupler input positions. The relative intensities of the UV wavelengths can be increased or decreased
significantly by this adjustment due to the chromatic aberrations of the lens in the optical fiber coupler.
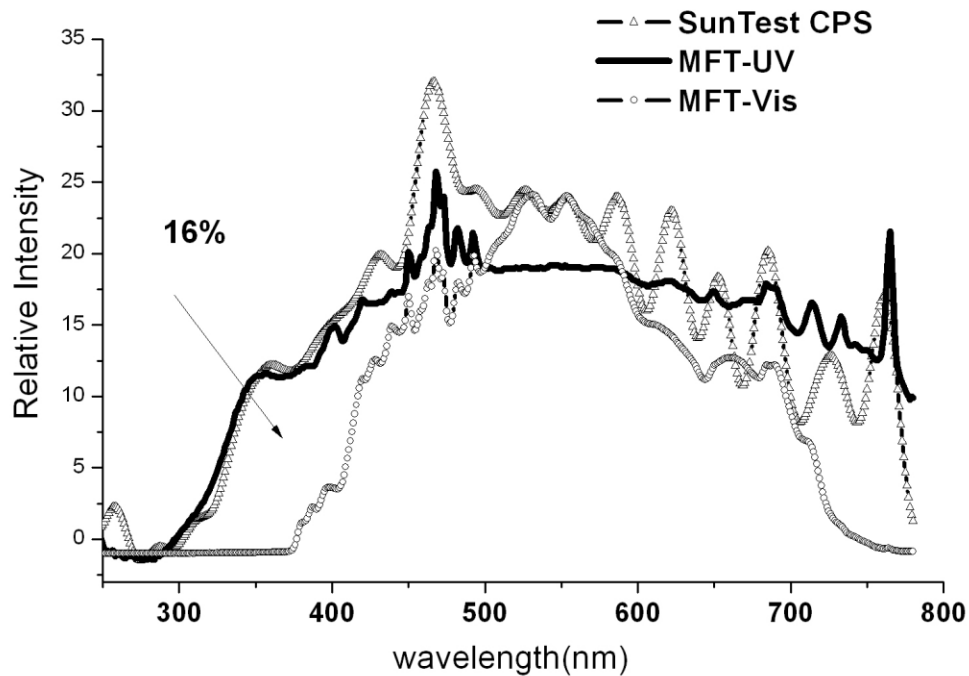
Figure 2. Spectral power distributions delivered through the fiber optic of the MFT in its conventional alignment for performing visible-only tests (MFT-Vis), and in its alignment to simulate natural daylight indoors, including the UV portion of the spectrum (MFT –UV). The spectral power distribution of the Atlas SunTest CPS, another xenon arc lamp exposure apparatus designed to simulate solar UV spectral power distributions, is also included for comparison

2.2 ILLUMINATION SPOT INTENSITY DISTRIBUTION AND CHROMATIC ABERRATION

As shown in figure 2, the desired spectral power distribution can be delivered to the illumination spot. Once that spectrum of light exits the fiber, it is focused with another set of simple lenses, and chromatic aberrations will also come into play. Focusing the various wavelengths to differing degrees can result in the high intensities being created unevenly across the spectrum. The position of the fiber optic connector with respect to the first lens in the focusing lens assembly determines the degree of focus for the light exiting the lens assembly. Adjusting that connector position, the shape and size of the focused spot could be altered, as well as the wavelength of light that was most nearly in tight focus. That adjustment allowed the exploration of the range of illumination conditions that could be produced in the small, intense focused spot on the sample. The focusing that occurred with the final lenses needed to be studied in order to make the adjustment that allows reproducible delivery of focused light across the entire spectral range.

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The focusing of the different wavelengths with the focusing lens assembly at the test head has been

examined by measuring directly the size of the focused spot at selected wavelengths. By placing a

bandpass filter into the beam, different wavelength regions were selected. A total of 6 filters—400, 450,

500, 600, and 700nm bandpass filters with a 70nm bandwidth, and a HOYA U-340 visible absorbing glass

filter—were used to cover the UV-Vis region. These narrow-wavelength light beams were directed

through the optical fiber, focused by the focusing lens assembly in the test head, and directed upward

into the 10X objective of an optical microscope (Olympus BX61). The black-and-white image recorded by

the microscope camera (Hamamatsu C10600) documented the size and shape of the beam as it

traversed the focal plane of the microscope optics. One of those images for 400nm light is shown in

figure 3a. That image can be analyzed to create a 3-D representation of the intensity distribution in the

spot (fig. 3b), or a line scan can trace the intensity across the diameter of the spot (fig. 3c). The ratio of

the area within full width at half maximum (FWHM) and the total area of the intensity for the entire

spot measures how much light was spread at the edges of the main spot. This metric describes the

tightness of the focus. All these image processing procedures and area calculations were carried out
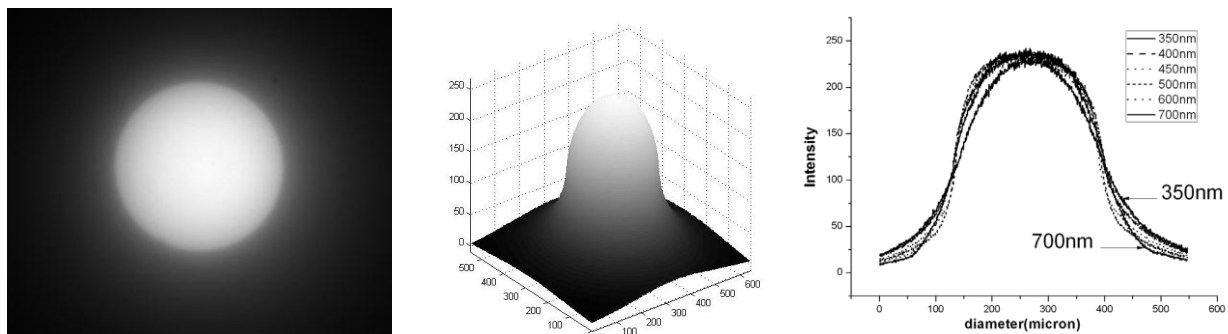
using Matlab program.

Figure 3. 3a (left). Photomicrograph of the illumination spot with a 400nm bandpass filter. 3b (center).
An intensity profile of the image shown in (a), showing the intensity distribution of the 400nm light. 3c
(right). Line scans of the intensity distributions measured from photomicrographs obtained for different
wavelengths. Despite the chromatic aberrations and the slightly different focus of the different
wavelengths, the congruence of the focused areas is very close.

The results of the intensity distributions at the various wavelengths are shown in figure 3c. While there

is some spreading of the beam at the very high and low ends of the 300-700 nm spectral range, the

deviation is reasonably small: measured ratios between the area within FWHM and the total area range

from 78% for 350nm to 83% for 500nm. This indicates that under this specific focus condition the

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illumination spot was focused almost uniformly throughout the whole spectral region. Other focus conditions—for example, tightly focusing at a wavelength in the red or in the UV—would lead to substantially poorer focus at the other end of the spectrum. Focusing the light around 450nm, then, near the midpoint of the UV-Vis region, tends to focus the entire spectral range reasonably well, and thus that focus will produce uniformly high intensities without distortion of the spectral power distribution that was delivered through the fiber.
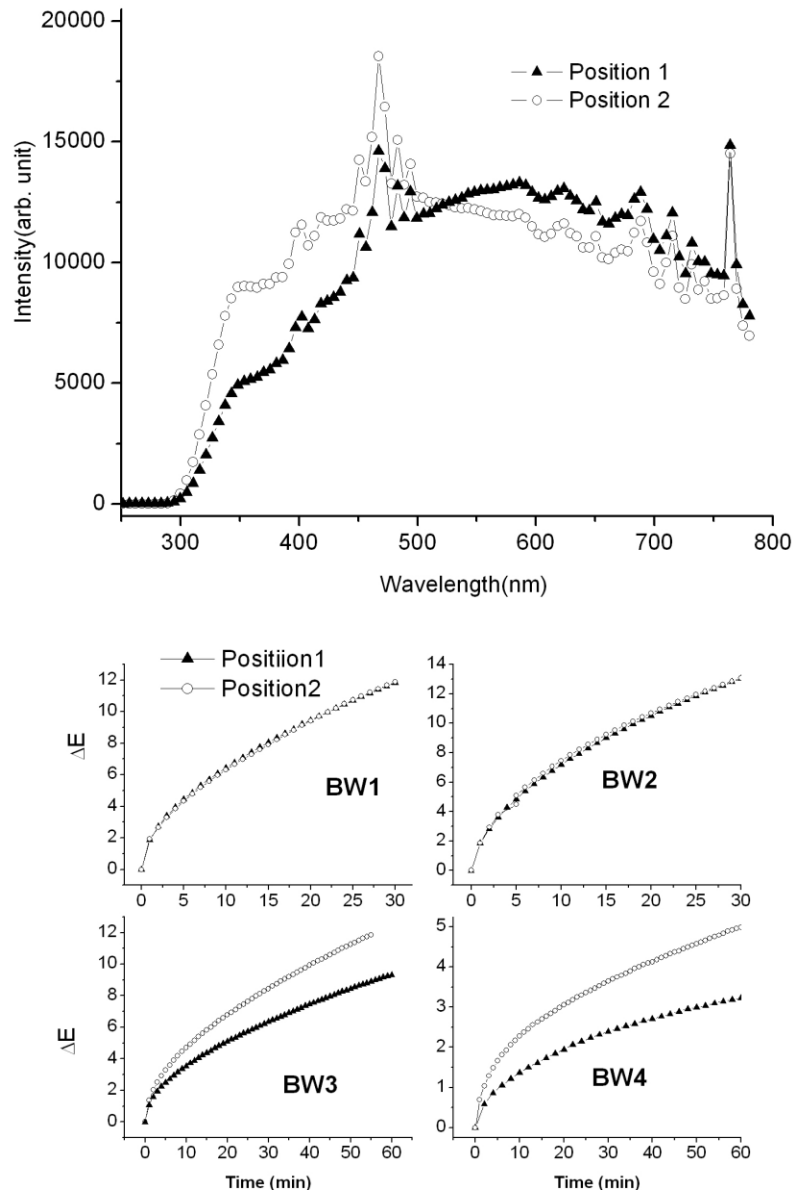

Figure 4. 4a (top). Spectral power distributions delivered for two different alignments of the lens in the fiber optic coupler. 4b (bottom). Blue Wool 1 to 4 fading curves for the corresponding two positions. The greater proportion of UV causes more rapid fading of the Blue Wools 3 and 4, while the fading of Blue Wools 1 and 2 is unaffected by the short wavelengths.
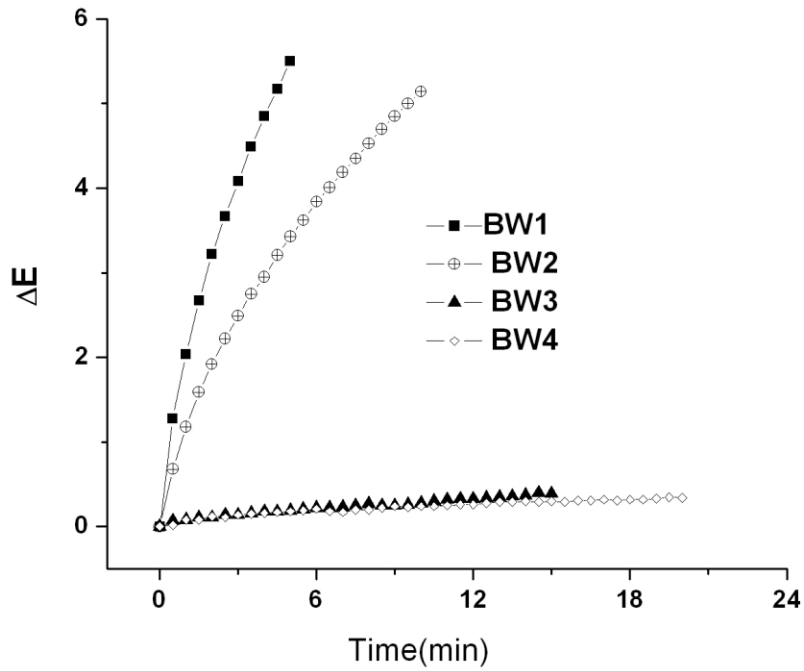
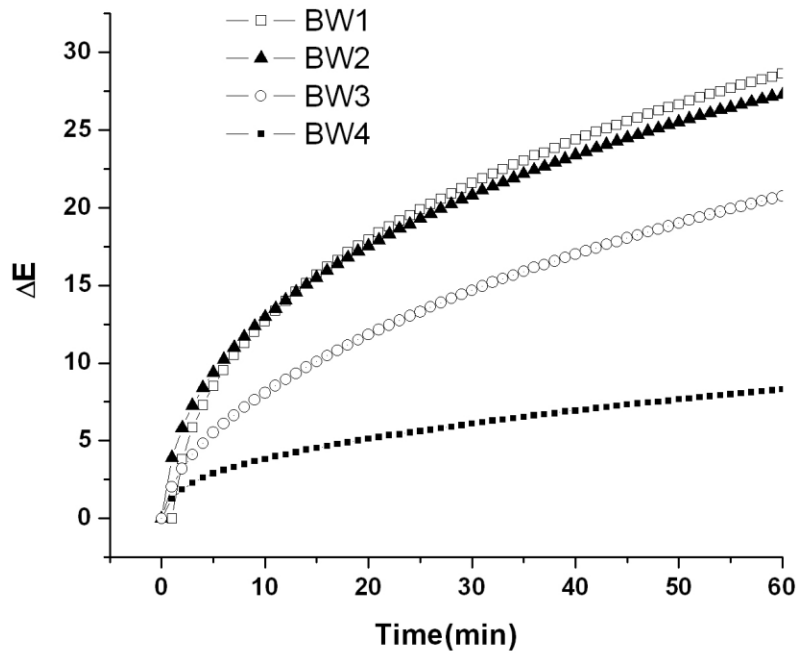Figure 5. Fading curves for Blue Wools 1 to 4 measured with the MFT using only visible light.

Figure 6. Fading curves for Blue Wools 1 to 4 measured with the MFT with light including UV wavelengths.
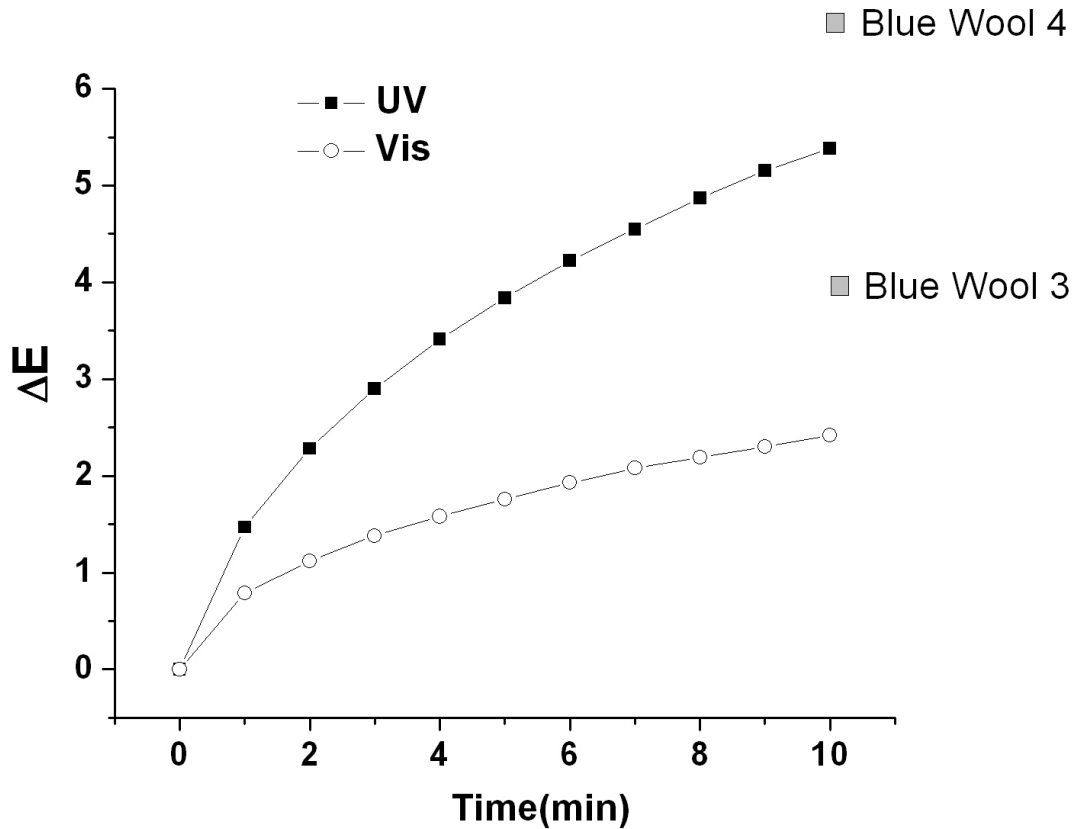
Figure 7. Fading curves of Rose Madder tested with the conventional instrument that excludes UV wavelengths (Visible) and the modified device that includes the UV portion of the spectrum (UV). The ΔE reached by Blue Wools 3 and 4 after 10 minutes are also indicated on the figure by the square symbols.

3. PERFORMANCE OF NEW INSTRUMENT CONFIGURATION

3.1 FADING RESULTS OF BLUE WOOL STANDARDS AND ROSE MADDER PIGMENT

For all the fading experiments carried out in this study, the luminous flux delivered by the fiber optic was set at 600 millilumens, and this light was then focused to a 0.28mm spot for both UV-Vis and Visible light exposures. This produced intensities of about 9.7 MLux in the focused spot. Fading tests were performed in the usual way (Whitmore et al. 1999), with the light-induced color changes (DE) calculated using the 1976 CIE equation.

Pigments fade because of chemical reactions that follow absorption of photochemically active wavelengths. Different pigments react differently to light at different wavelength regions. It is well established that the ISO Blue Wools 1 and 2 are more sensitive to visible light, while Blue Wool 3 and

higher are more susceptible to UV radiation (McLaren 1956). His wavelength dependence can be demonstrated by performing two fading tests, with two spectral power distributions that differed in the relative intensities of the UV and the visible. Shown in figure 4a, alignment position 1 had higher intensity in visible region (> 500nm) than that of position 2, while position 2 contained more intensity in the UV region. The fading curves of Blue Wools 1 to 4 exposed to these two spectral power distributions are shown in figure 4b. The fading rates for Blue Wools 1 and 2 did not change with the alignments. However, for Blue Wools 3 and 4, the fading rates increased dramatically when the UV content of the light was increased. These results are consistent with earlier measurements (McLaren 1956).

This UV sensitivity of the Blue Wools 3 and higher is illustrated in the tests with the MFT using either visible light only (i.e., the typical configuration that excludes UV wavelengths with a cutoff filter) or with visible plus UV wavelengths. Figure 5 shows the typical fading curves for Blue Wools 1-4 using visible light only in the MFT system. The fading rates of Blue Wools 3 and 4 are very slow, because these dyes are much less sensitive to visible light. When the Blue Wools were exposed to light that included the UV wavelengths, the fading rates of both Blue Wools 1 and 2 increased moderately, while the Blue Wools 3 and 4 faded according to relative rates that are closer to those expected for the standards. In these tests Blue Wool 2 faded slightly faster with the UV included, and this brought its fading curve almost coincident with that of Blue Wool 1 under the same conditions. The reasons for this discrepancy are still being explored. Nevertheless, the dramatic fading rate increase due to UV light for both Blue Wool 3 and 4 makes them comparable to other measurements, for example, those reported by Feller and Johnston-Feller (1979).

To test the performance of the UV-MFT on other colorants, fading tests with and without the UV portion of the spectrum were done on a commercial genuine Rose Madder watercolor paint (Winsor & Newton) painted on a hot-pressed watercolor paper. As shown in figure 7, rose madder is very sensitive to UV radiation. The fading rate doubled with the inclusion of UV wavelengths. Under the experimental condition, the fading rate of Rose Madder fell in between Blue Wool 3 and Blue Wool 4, which is reasonable for this particular pigment.

3.2 PROPOSED PROTOCOLS FOR FADING INCLUDING NEAR-UV WAVELENGTHS

In order to get consistent results for fading tests containing UV radiation, it is important to follow the proposed protocols, especially for the microfading systems without UV-sensitive spectrometers. First, an

appropriate filter, such as KG-2 glass or borosilicate glass with a water filter, is required to generate the desired spectral window. Then, the illumination fiber coupler end is adjusted to intercept the light beam at the position having the desired spectrum. This adjustment can also be made by delicate movement of the lamp condenser lens. (Using the condenser lens for this spectral tuning will require re-optimizing the focus of the lenses at the test head.) The spectrum of near-UV wavelengths in the beam should be similar to that of daylight indoors or the Suntest CPS. For systems with spectrometers sensitive only to the visible region, this UV spectrum can be roughly achieved by tuning the visible spectrum to have an intensity at 400 nm about 65% of the intensity at 500nm. After that, a bandpass filter to allow only 450nm light into the fiber is placed into the filter holder on the lamp and the test head lenses are adjusted to optimize the focus at that wavelength. This condition should then produce reasonably good focus across the entire 300-700nm region. Finally, Blue Wool standards 1-4 are tested to ensure the correct relative fading rates.

ACKNOWLEDGMENTS

REFERENCES

Feller, R., and R. Johnston-Feller. 1979. Use of the international standards organization's Blue-wool standards for exposure to light. II. Instrumental measurement of fading. In *AIC Preprints,* American Institute for Conservation 7th Annual Meeting, Toronto, Canada, Washington, D.C.: AIC. 30-36.

McLaren, K.1956. The spectral regions of daylight which cause fading. *Journal of the Society of Dyers and Colourists*. 72: 86-99.

Whitmore, P. M., X. Pan, and C. Bailie. 1999. Predicting the fading of objects: identification of fugitive colorants through direct nondestructive lightfastness measurements. *Journal of American Institute for Conservation* 38: 395-409.

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SOURCES OF MATERIALS

Diode array spectrometer (PDA USB-512 element) and software

Control Development Inc.

2633 Foundation Drive

South Bend, IN 46628

KG2 glass, cat. no. FSQ-KG2, HOYA U-340 glass, cat. No. FSQ-U340

Newport Corp.

1791 Deere Avenue

Irvine, CA 92606

Borosilicate glass, cat. no. WG-305

Edmund Scientific

101 East Gloucester Pike

Barrington, NJ 08007

Olympus BX61 Microscope, Hamamatsu C 10600 camera

B&B Microscopes, Ltd.

535 Rochester Road

Pittsburgh, PA 15237

Rose madder watercolor paint

Art supply stores

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MICROFADE TESTING OF 19TH CENTURY IRON GALL INKS

SEASON TSE, SHERRY GUILD, VALERIA ORLANDINI

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ABSTRACT - The Oriel Microfade Tester (O-MFT) was used to test five sample sets of 19th century iron gall inks, with and without aqueous treatments, and after previous light exposure. The results showed that these inks belong in the category of BW1-3 which means they have 'high light sensitivity'. There are very light sensitive components in the ink which can be partially removed by aqueous treatments resulting in lower sensitivity to light. In addition, calcium phytate reacts with some inks making them less light sensitive.

PRUEBA DE MICRODECOLORACIÓN DE TINTAS FERROGRÁFICAS DEL SIGLO 19: RESUMEN – Se utilizó el Tester de Microdecoloración Oriel (O-MFT) para probar cinco conjuntos de muestras de tintas ferrográficas del siglo 19, con y sin tratamientos acuosos y después de exposición a la luz. Los resultados demostraron que estas tintas corresponden a la categoría de BW1-3, lo que significa que poseen una 'alta sensibilidad a la luz'. Hay muy pocos componentes sensibles a la luz en la tinta que se pueden remover parcialmente mediante tratamientos acuosos para lograr una menor sensibilidad a la luz. Asimismo, el fitato de calcio reacciona con determinadas tintas y las hace menos sensibles a la luz.

1. INTRODUCTION

Since 2008, the Oriel Microfade Tester (O-MFT) has been used at the Canadian Conservation Institute for direct determination of light sensitive materials. The first of two testers was built based on Paul Whitmore's original design (Whitmore 1999), and the second was built with a more portable light source. The materials tested include herbaria specimens in Catherine Parr Traill scrapbooks, Queen Victoria's written dedication and signature in iron gall ink, 19th century photographs, wool yarns with natural dyes and mordants, treatment materials such as digitally printed textiles and paper, and oil and acrylic paintings. Among the historic colorants and media tested, iron gall inks were found to be among the most light sensitive (BW1-3). Since many Canadian historic documents written in iron gall ink suffer from ink fading rather than ink corrosion, it was necessary to understand the effect of light exposure on historic iron gall inks, in order to determine exhibition protocols.

1.1 COLOR OF IRON GALL INKS

The color of historic iron gall inks vary from light brown to dark blue black, and their fading properties also vary. It is well known that both high (pH above 8) and low (pH below 4) pH can cause these inks to change color (Krekel 1999, Reissland 2001). Other factors that influence ink color include the type and concentration of tannin in the gallic acid source, the proportion of Fe(II) and Fe(III) in the iron source, the ratio of gallic acid to iron ions and the method of preparation (Krekel 1999, Sistach *et al* 1993, Sistach *et al* 1999, Daniels 2000). Since historical iron gall inks are made from natural products, all of these factors play a role in determining the properties of the inks, and result in the wide range of color and stability of these inks.

1.2 LIGHT SENSITIVITY OF IRON GALL INKS

When applied on textiles, gallotannin dyestuff with iron mordants is reported to have medium light sensitivity (BW5-6) (Hofenk de Graaff, 2004). On paper these ferro-gallotannin colorants are more light sensitive. The difference may be due to the larger size of the color complex, better adsorption and higher concentration as a dye used for textiles compared to iron gall ink used on paper.

The light sensitivity of iron gall inks has been studied by Reissland and Cowan (2002). Using laboratory prepared and aged inks, they systematically evaluated the degree of color change as a function of different molar ratios of iron ions and gallic acid. They found that most of the color change from the inks are a result of increase lightness (L*) and increase yellowness or loss of blueness (b*). They also observed that after exposure to an intermediate stage of oven aging, the inks that have higher ratio of iron sulphate relative to gallic acid, tend to be more light sensitive. This is attributed to iron catalyzed oxidation of ink/paper components forming light sensitive components. At the same degree of heat aging, inks that have higher proportion of gallic acid are less light sensitive, possibly because of the antioxidant qualities of gallic acid. With further oven aging this trend reversed, suggesting that the light sensitivity of inks may be a function of the stage of aging. The study confirmed that iron gall inks are light sensitive, the degree of sensitivity is a function of their composition and exposure history.

1.3 IRON GALL INK TREATMENTS

The treatments investigated in this study are aqueous deacidification treatment using calcium

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bicarbonate for neutralizing acids in iron gall inks; paper simmering – an extreme washing treatment that is very effective in removing water soluble compounds including acids and Fe(II) ions, and degradation products; and calcium phytate. Calcium phytate is one of the most effective and proven treatments for preservation of iron gall ink documents over the past 15 years. Made from naturally occuring phytic acid, calcium phytate acts as an antioxidant by forming strong complexes with excess Fe(II) ions in the ink, preventing them from catalyzing oxidation of the substrate, at the same time without destroying the ink complex (Neevel 2001). A detail background of this treatment and an optimized procedure can be found in the Ink Corrosion Website (Reissland *et al* 2007).

1.4 MICROFADE TESTING OF HISTORIC INKS

In this study we use historic inks instead of lab prepared inks. While this eliminates the need to extrapolate results from model inks, one should accept that the results may not be representative due to large variations in historic ink compositions and matrix. The selected ink samples are from an ongoing study evaluating the effect of aqueous treatments on iron gall inks, where five original 19th century iron gall ink documents were subjected to 18 separate treatments (Orlandini 2010). Eight of the 18 sets of treated samples were subjected to further accelerated aging by heat, high humidity and high intensity light (Tse *et al*, 2010). This study investigates the effects of selected treatments on light sensitivity of iron gall inks.

2.   EXPERIMENTAL

The Oriel Microfade Tester (O-MFT) is shown in Figure 1. The settings and the characteristics of the light spot are summarized in Table 1. Details of the construction and operation of the tester were previously described by Whitmore (1999), and summarized by Druzik (2010). One modification was made from the Whitmore design. Two sets of doublet achromat lenses were used for illumination and collection, instead of the singlet lenses in the original design. The diameter of the light spot was estimated to be 0.3mm using image analyses of the effective faded spot (Young 2008). An Endoscope pencamera was used to locate and document the light spot on the test areas. The luminous flux of the light spot was measured using ILT900 spectroradiometer and an integrating sphere calibrated for point source.

Microfading tests were carried out for 10-minute periods, and spectral data was collected every 30 seconds. Data processing was done using the Getty Spectralviewer, software developed by Lionel Keene.

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Prior to testing of ink samples, the fading rates of ISO blue wool standards (BW1-3) were measured each day. Replicates of 4to 6 measurements were carried out for each ink, the number of replicates was determined by the homogeneity of the inks. Fading rates are expressed as total color change (CIE dE'94) as a function of time. The light sensitivity category for the ink is determined by comparing the total color change after 10 minutes exposure, to that of the blue wool standards.
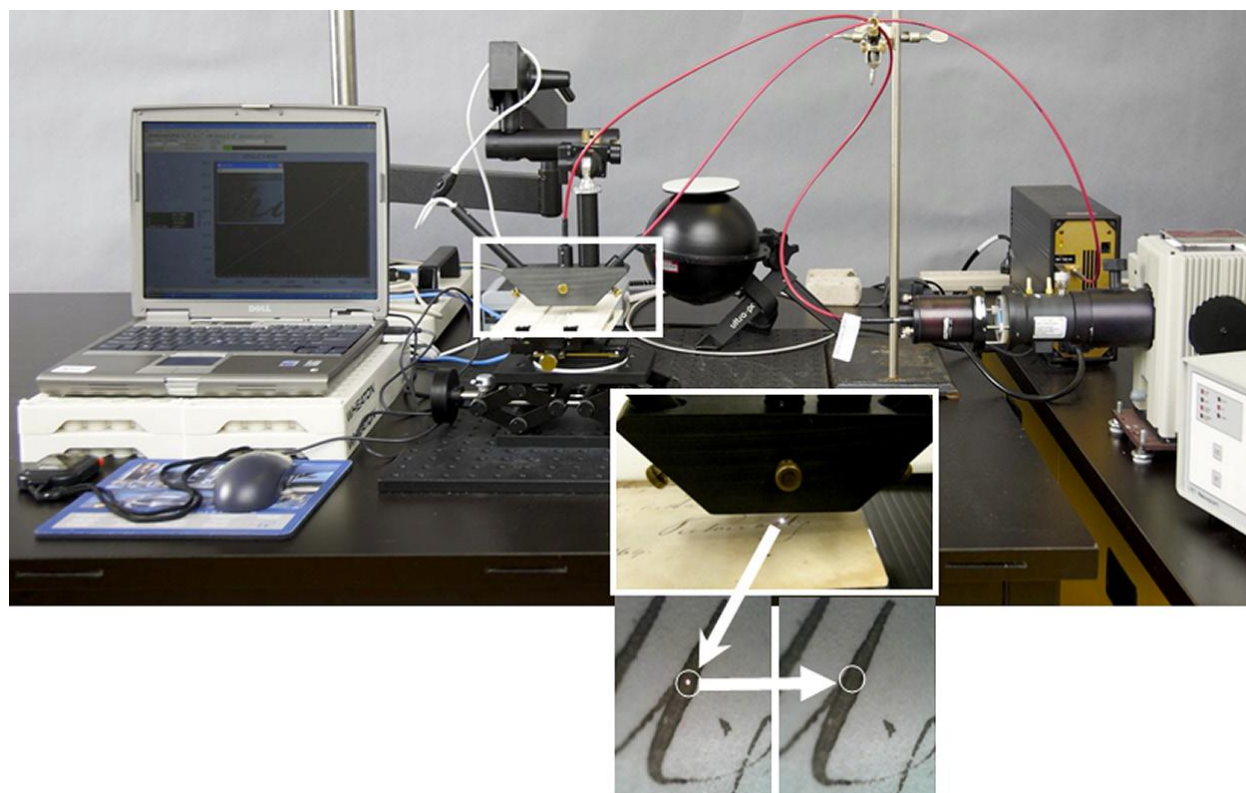

Figure 1. The CCI benchtop Oriel microfade tester. The small white spot in the magnified image of the inkline is the light spot viewed through a neutral density filter. The adjacent image showed the same area, without the light spot, after 10 minutes of fading.

Description of treatment and light exposure conditions for ink samples selected for microfade testing are summarized in Table 2. Description of the five ink documents are summarized in Table 3 along with the results. The visible condition of the inks were documented using the Netherlands Institute for Cultural Heritage (ICN) rating system (Reissland and Hofenk de Graaff 2000). The presence and recurrence of the ferrous (Fe(II)) and ferric ions (Fe(III)) in all samples were tested using bathophenanthroline indicator strips, with and without ascorbic acid, and the numeric values are obtained by comparing test paper color to a calibrated color chart developed at CCI (Tse *et al* 2010).

3. RESULTS

The microfade tester allows one to carry out *in-situ* fading tests in a micro-destructive manner. The advantage of direct light sensitivity measurements of these historic inks is that the results take into account the differences in ink compositions, substrate matrices, environmental exposure histories and state of deterioration, and allow one to measure the effect of the treatments on their light stability. 3.1 CHANGES OF INKS WITH MICROFADING

Figure 2 shows the fading rates of all 5 sets of inks. Table 3 summarizes the total color change (dE'94), change in lightness (L*), red-green (a*) and yellow-blue (b*) after 10 minute testing. An example to illustrate the progressive color change (dE'94, L*, a* and b*) of the inks is shown in figure 3 using the untreated Sample 2 ink.
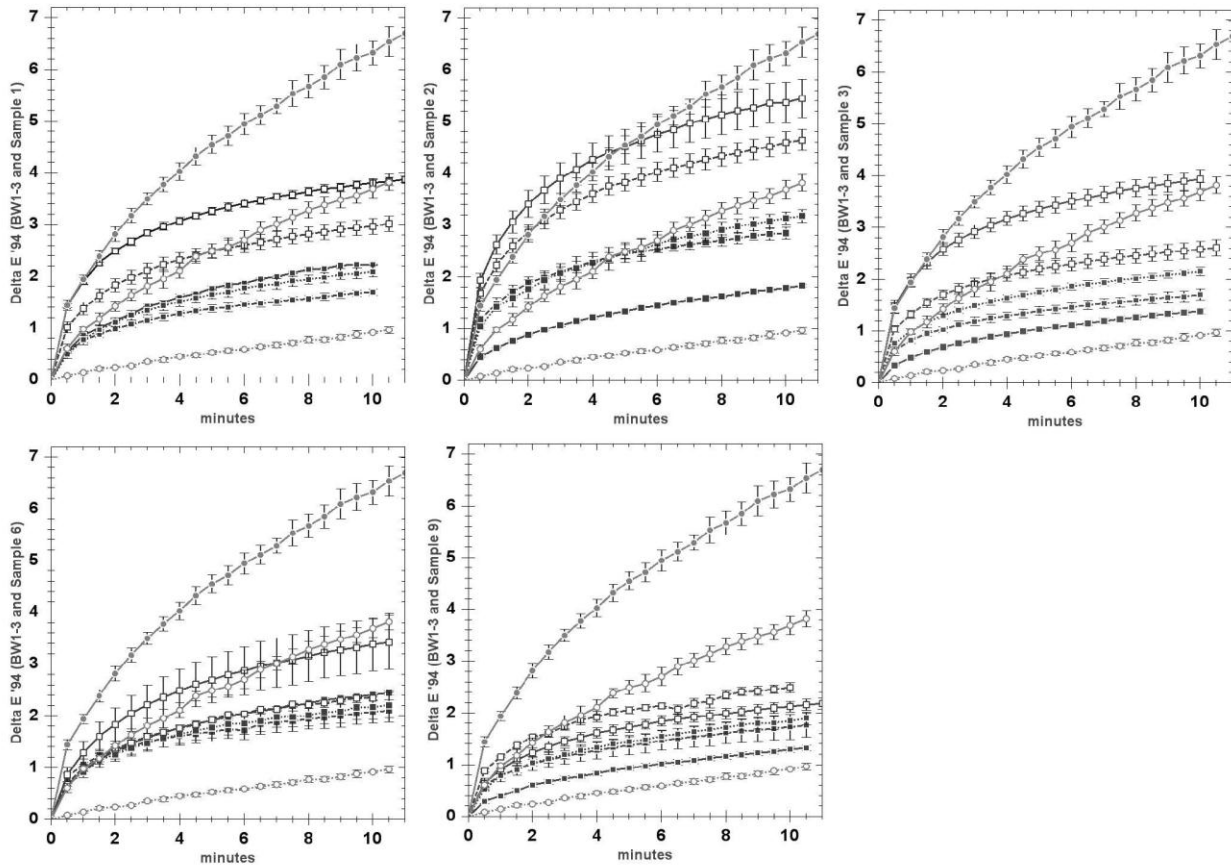

Figure 2. Fading curves of ISO Bluewool 1-3 and five iron gall inks with treatment, without treatment and with light exposure (-●- BW1, -○- BW2, ○ BW3, -□- Control, ---□--- control lightaged,

■ Calcium bicarbonate, --- ■ --- Simmering, -n- calcium phytate).

Based on the total color difference (dE'94) data after 10 minutes, all the inks have sensitivity equivalent to BW1-3, and they are all categorized as having "high light sensitivity". Table 4 shows that the estimated light dose to just noticeable difference (JND) for these inks are between 0.22-1.5 Mlux-hr, with UV, and 0.3-3.0 Mlux-hr, without UV. These light dose are estimates based on averaged values obtained from literature review. The uncertainty in each dose estimate ranges approximately to the value for the adjacent Blue Wool (Michalski 1987; 2010). The time it takes to result in just noticeable difference will depend on the light intensity or lux level, and the duration of light exposure. The longer the exposure time or the higher the light intensity, the sooner visible change will occur. The CCI Light Damage Calculator, an online tool being developed by Stefan Michalski, is designed to help users visualize the impact of these lighting decisions.

Of the five inks, Sample 2 is the most sensitive to light, and Sample 9 is the least sensitive. Most of the color change results from an increase in lightness (L*) and yellowness (b*). This is consistent with previous observations with lab-prepared inks (Reissland & Cowan 2002).

The shape of the fading curves of the five inks is consistent with Type II curves described by Giles (1968) and Cox-Crews (1987). There is an initial rapid change followed by a slower and constant change (fig. 2). Figure 4 shows the dE'94 of the inks after 1 minute testing. Samples 1, 2 and 3 are have the highest initial fading rate, higher than or equal to BW1; Sample 6 and 9 are close to BW2. Fading subsequently slowed down. Figure 5 shows that after 10 minutes, inks 1, 2 and 3 are close to BW2 and inks 6 and 9 are close to BW3. This behaviour is consistent with dyes that have small portions that are molecularly dispersed and a larger portion in the form of aggregates in the substrate (Cox-Crews 1987). With these inks, the highly light sensitive components could be these smaller particles of ink complexes or degradation products on the surface of the ink line.
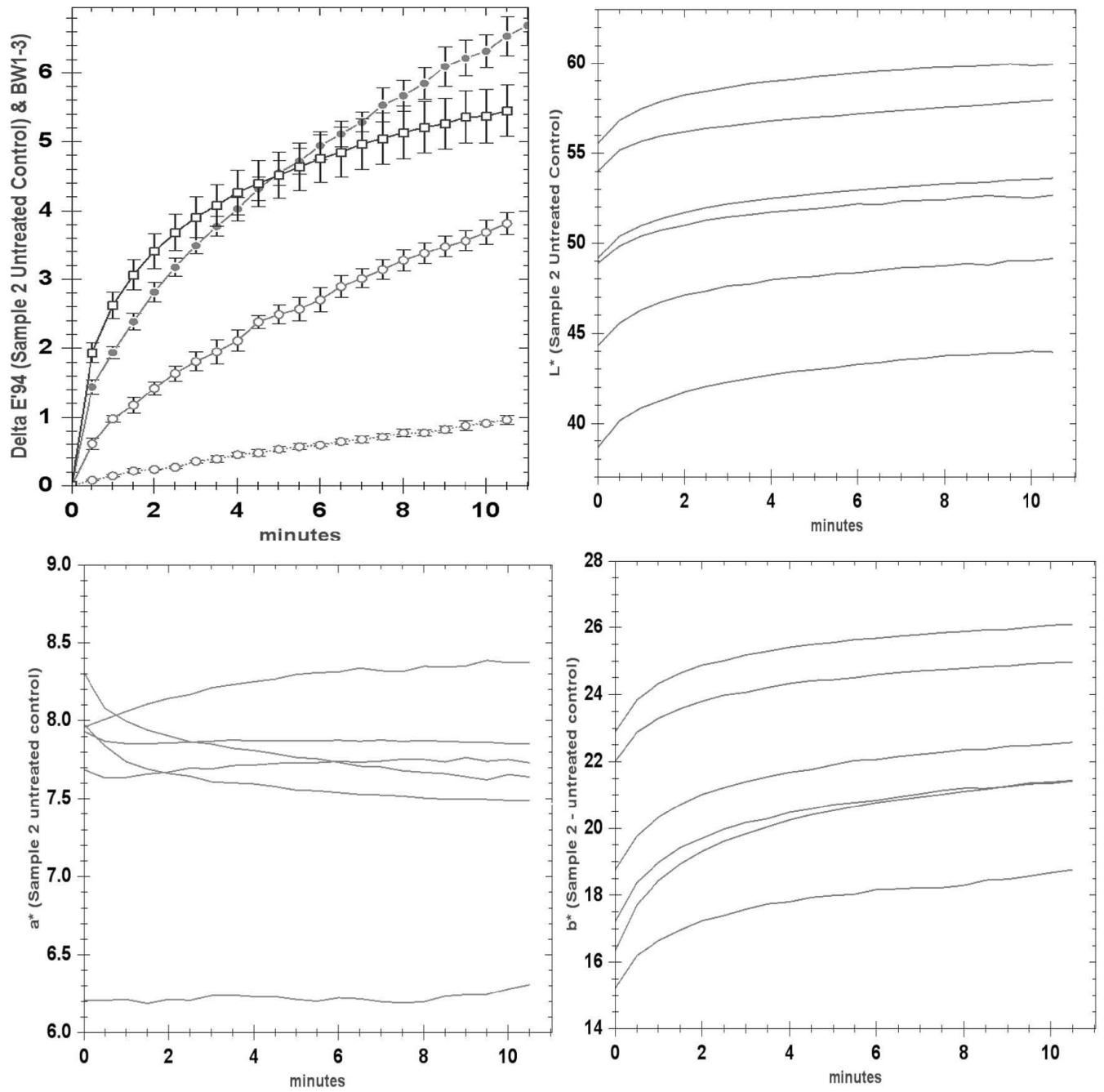
Figure 3. Sample 2 - change of dE'94, L* (lightness); a* (red-green) and b* (yellow-blue) (dE'94: -●I-
BW1, -○- BW2, ○ BW3, -□- Sample 2 ink untreated control).
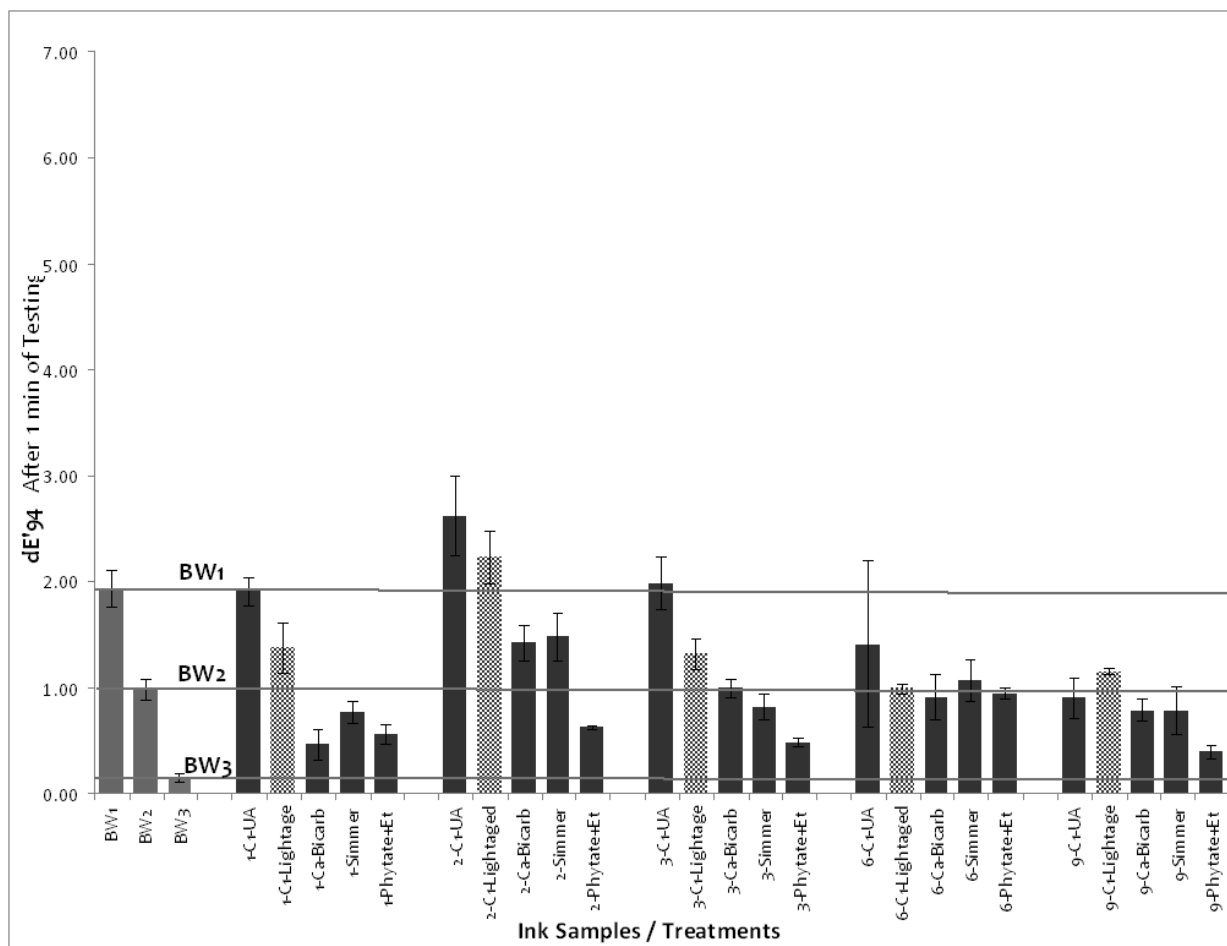
Figure 4. Total color change (dE'94) after 1 minute testing: five sets of inks.

3.2 EFFECT OF TREATMENT ON LIGHT SENSITIVITY

Figure 3 and table 3 show the fading curves of the five inks with and without treatment, and with light exposure. With all the inks, the untreated control is consistently most light sensitive. Aqueous treatment and previous light exposure reduced the fading rates of the ink to different degrees for the different inks. Previous light exposure will cause break down of some of the light sensitive molecules resulting in lower concentrations of these molecules, hence slower fading rates.

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Figure 5. Total color change (dE'94) after 10 minutes testing: five sets of inks.

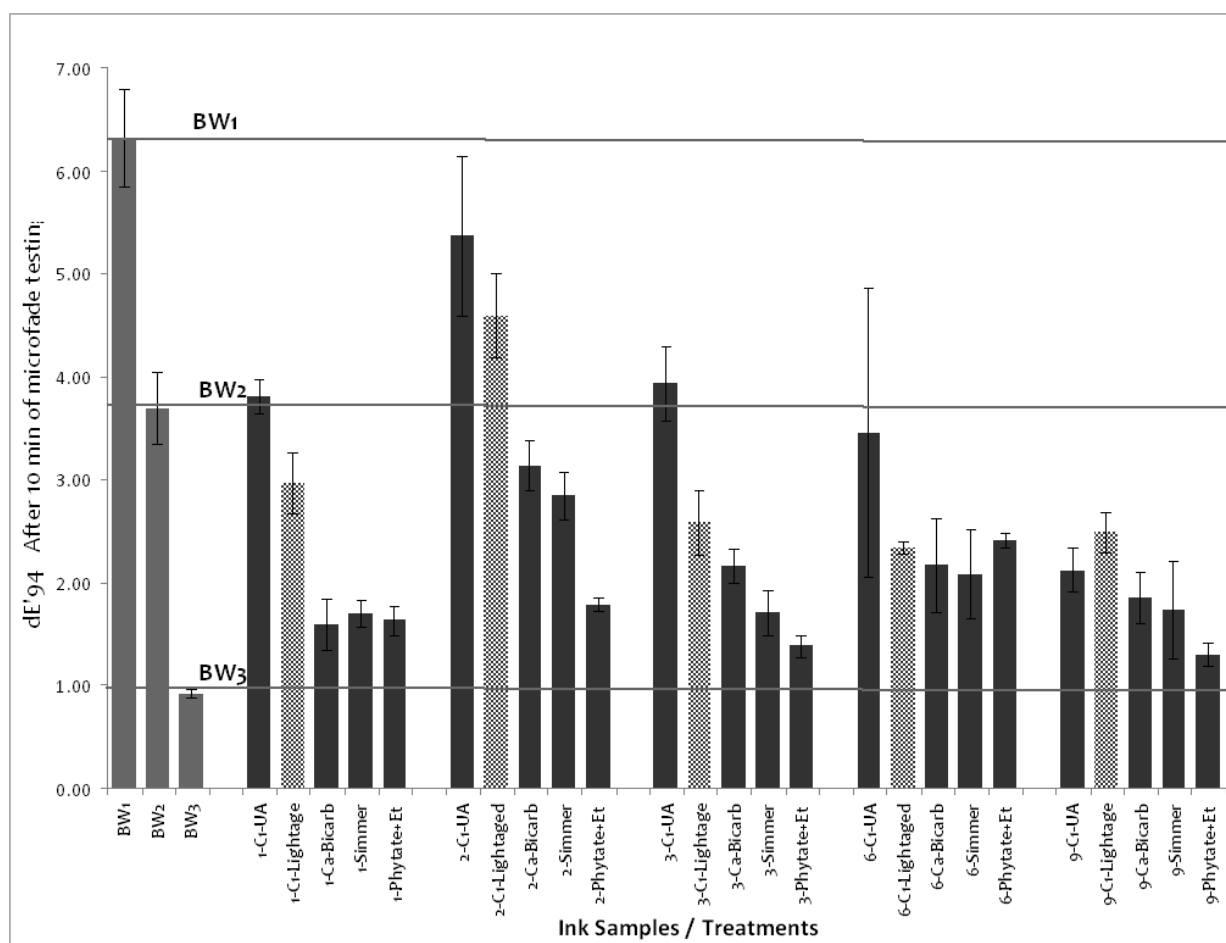With aqueous treatments, the decreased fading rates is likely due to solubilization and removal of the highly light sensitive smaller particles and degradation products. Simmering, a more aggressive treatment because of its higher temperature, is expected to remove more ink components compared to calcium bicarbonate treatment, and should therefore have greater impact in light sensitivity of the ink. But the difference between the two treatments is marginal for four out of the five inks. This suggests that increasing the temperature of the treatment bath does not remove more of these light sensitivity components, and that most of these are removed in room temperature treatments. Calcium phytate, on the other hand, is expected to have similar impact compared to calcium bicarbonate because of similar treatment temperatures. But with three out of five inks, phytate treated inks have measurably lower light sensitivities than bicarbonate. This additional benefit of calcium phytate may be due to its ability to act as an antioxidant by forming an insoluble complex with iron (II) ions, thereby stabilizing the ink complex against light damage.

Table 1. O-MFT Instrument settings and characteristics of the light spot.

	Without Digital Exposure Control	With Digital Exposure Control
Power Supply *Current* (A)	5.6	5.2
***Voltage* (V)**	15.5	15.3
***Power* (W)**	86	81
Digital Exposure Controller *Current* (µA)	-	46.73
***Integration Time* on Labsphere spectralon white standard (Sec):** 0.009472		
Flux (ILT-900; mlm): 320		
Diameter of spot: 0.3 mm		
Illuminance (spot): 4.53 Mlux		
Data collection frequency: 30 seconds		
Duration of test: 10 minutes		
Dosage for 10 minute testing: 755 klux-hr		

Table 2. Description of treatment and light exposure conditions applied to ink samples.

	Description of treatment and light exposure
Control	No treatment
Calcium bicarbonate	RO water + 0.011M Ca(HCO3)2; 20min each
Simmering	Ethanol immersion + alkaline water simmer - pH 8.3 Ca(OH)2; 90°C; 15min
Calcium phytate	Pre-wet with ethanol spray; calcium phytate + 0.011M Ca(HCO3)2; 20min each
Light exposure	Fluorescent light bank (14; 40-watt, 4-foot 1157 Vita-lite); vertically mounted; no UV filters; 20-25°C, 40±5%RH; 10 weeks; averaged accumulated irradiance: 5564 kJ/cm2; total light exposure: 3.71Mlux-hr.

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Table 3.   Change of dE'94, L*, a*, and b* of inks after 10-minute testing.

	ID	dE'94	std. dev.	dL*	std. dev.	da*	std. dev.	db*	std. dev.
	BW1	5.95	±0.72	3.59	±0.77	-1.37	±0.07	8.98	±3.59
	BW2	3.71	±0.25	2.01	±0.18	0.36	±0.05	7.01	±0.37
	BW3	0.99	±0.13	0.73	±0.10	-0.35	±0.10	1.42	±0.23
Sample 1	c.1856 cream colour ledger, wove cotton rag paper with thin blue lines; ink dark brown. ICN rating: 1; Fe^{2+}: 50+ ;Fe^{3+}:50+ ; FTIR-ATR: gelatin; μXRF-ink: Fe, K								
	Control	3.80	±0.17	3.02	±0.21	-0.02	±0.32	2.52	±0.38
	Control + lightaged	2.97	±0.30	2.26	±0.23	0.14	±0.28	2.04	±0.34
	Calcium bicarbonate	1.59	±0.24	1.90	±0.28	-0.11	±0.42	1.22	±0.31
	Simmer at 90°C	1.70	±0.13	1.50	±0.09	-0.13	±0.29	0.80	±0.45
	Calcium phytate	1.63	±0.14	1.67	±0.23	-0.23	±0.21	0.80	±0.61
	Calcium phytate + light exposed	1.50	±0.40	1.28	±0.26	-0.26	±0.18	0.35	±0.67
Sample 2	c.1849 greyish cream colour ledger; wove cotton rag paper with thin blue lines; ink light brown ICN rating: 1; Fe^{2+}: ~10; Fe^{3+}:50++; μXRF-ink: Fe, K								
	Control	5.37	±0.78	4.39	±0.62	-0.11	±0.39	3.76	±0.76
	Control + lightaged	4.60	±0.41	3.82	±0.37	-0.24	±0.32	2.55	±0.58
	Calcium bicarbonate	3.13	±0.25	2.65	±0.13	-0.62	±0.23	1.33	±0.62
	Simmer at 90°C	2.84	±0.23	2.31	±0.18	-0.84	±0.02	0.28	±0.34
	Calcium phytate	1.78	±0.06	1.54	±0.05	-0.82	±0.07	-0.43	±0.15
	Calcium phytate + light exposed	1.18	±0.06	1.06	±0.03	-0.58	±0.01	-0.70	±0.26
Sample 3	c.1864 blue ledger; laid cotton rag paper with visible chain and laid lines; ink light brown with dark strokes; ICN rating: 1; Fe^{2+}: ~25; Fe^{3+}: ~25; FTIR-ATR: gelatin; μXRF-ink: Fe, Ca, S								
	Control	3.93	±0.35	3.22	±0.30	-0.49	±0.36	2.06	±0.86
	Control + lightaged	2.58	±0.31	2.12	±0.22	-0.52	±0.10	0.72	±0.39
	Calcium bicarbonate	2.15	±0.16	1.81	±0.12	-0.60	±0.09	0.42	±0.42
	Simmer at 90°C	1.77	±0.25	1.49	±0.19	-0.45	±0.09	0.34	±0.24
	Calcium phytate	1.38	±0.11	1.19	±0.16	-0.58	±0.07	-0.10	±0.30
	Calcium phytate + light exposed	0.83	±0.06	0.64	±0.15	-0.40	±0.10	-0.43	±0.21
Sample 6	c.1846 cream ledger; wove cotton rag paper with no lines; ink thin dark brown strokes ICN rating: 1; Fe^{2+}: 50; Fe^{3+}:50+++; FTIR-ATR: gelatin; μXRF-ink: Fe, K								
	Control	2.95	±1.00	2.30	±1.19	0.61	±0.18	2.51	±1.18
	Control + lightaged	2.34	±0.06	1.77	±0.04	0.19	±0.20	1.97	±0.01
	Calcium bicarbonate	2.17	±0.46	1.69	±0.40	-0.12	±0.13	1.55	±0.22
	Simmer at 90°C	2.08	±0.43	1.66	±0.39	-0.47	±0.34	0.74	±0.32
	Calcium phytate	2.41	±0.08	1.86	±0.15	-0.28	±0.27	1.78	±0.19
	Calcium phytate + light exposed	1.40	±0.26	1.06	±0.25	-0.56	±0.13	0.62	±0.02
Sample 9	c.1846 green ledger; wove cotton rag paper with no lines; ink light brown ICN rating: 1; Fe^{2+}: ~10; Fe^{3+}:~10; μXRF-ink: Fe, Cu, Mn, Ca, Cl, K								
	Control	2.06	±0.02	1.91	±0.20	-0.70	±0.14	0.56	±0.44
	Control + lightaged	2.49	±0.19	2.11	±0.18	-0.69	±0.01	0.77	±0.32
	Calcium bicarbonate	1.85	±0.25	1.59	±0.24	-0.71	±0.08	0.09	±0.19
	Simmer at 90°C	1.73	±0.48	1.38	±0.54	-0.61	±0.08	-0.22	±0.57
	Calcium phytate	1.30	±0.11	1.12	±0.12	-0.63	±0.05	-0.20	±0.26
	Calcium phytate + light exposed	1.20	±0.08	1.04	±0.05	-0.53	±0.06	-0.44	±0.15

Table 4. Light sensitivity categories and light dose estimates for fading of inks.

	Treatment Description	dE'94 at 10 min	std. dev.	BW equivalence	Estimated light dose to JND ; Mlux-hr	
					with UV	no UV
	BW1	5.95	±0.72	High sensitivity to light	0.22	0.3
	BW2	3.71	±0.25		0.6	1
	BW3	0.99	±0.13		1.5	3
Sample 1						
	Control	3.80	±0.17	~BW2	0.6	1
	Control + lightaged	2.97	±0.30	BW2-BW3	0.6 -1.5	1 - 3
	Calcium bicarbonate	1.59	±0.24	BW2-BW3	0.6 -1.5	1 - 3
	Simmer at 90°C	1.70	±0.13	BW2-BW3	0.6 -1.5	1 - 3
	Calcium phytate	1.63	±0.14	BW2-BW3	0.6 -1.5	1 - 3
	Calcium phytate+lightaged	1.50	±0.40	BW2-BW3	0.6 -1.5	1 - 3
Sample 2						
	Control	5.37	±0.78	BW1-BW2	0.22- 0.6	0.3 - 1
	Control + lightaged	4.60	±0.41	BW1-BW2	0.22- 0.6	0.3 - 1
	Calcium bicarbonate	3.13	±0.25	BW2-BW3	0.6 -1.5	1 - 3
	Simmer at 90°C	2.84	±0.23	BW2-BW3	0.6 -1.5	1 - 3
	Calcium phytate	1.78	±0.06	BW2-BW3	0.6 -1.5	1 - 3
	Calcium phytate+lightaged	1.18	±0.06	BW2-BW3	0.6 -1.5	1 - 3
Sample 3						
	Control	3.93	±0.35	BW2	0.6	1
	Control + lightaged	2.58	±0.31	BW2-BW3	0.6 -1.5	1 - 3
	Calcium bicarbonate	2.15	±0.16	BW2-BW3	0.6 -1.5	1 - 3
	Simmer at 90°C	1.70	±0.22	BW2-BW3	0.6 -1.5	1 - 3
	Calcium phytate	1.38	±0.11	BW2-BW3	0.6 -1.5	1 - 3
	Calcium phytate+lightaged	0.83	±0.06	BW3	1.5	3
Sample 6						
	Control	3.46	±1.40	~BW2	0.6	1
	Control + lightaged	2.34	±0.06	BW2-BW3	0.6 -1.5	1 - 3
	Calcium bicarbonate	2.17	±0.46	BW2-BW3	0.6 -1.5	1 - 3
	Simmer at 90°C	2.08	±0.43	BW2-BW3	0.6 -1.5	1 - 3
	Calcium phytate	2.41	±0.08	BW2-BW3	0.6 -1.5	1 - 3
	Calcium phytate+lightaged	1.40	±0.26	BW2-BW3	0.6 -1.5	1 - 3
Sample 9						
	Control	2.12	±0.21	BW2-BW3	0.6 -1.5	1 - 3
	Control + lightaged	2.49	±0.19	BW2-BW3	0.6 -1.5	1 - 3
	Calcium bicarbonate	1.85	±0.25	BW2-BW3	0.6 -1.5	1 - 3
	Simmer at 90°C	1.73	±0.48	BW2-BW3	0.6 -1.5	1 - 3
	Calcium phytate	1.30	±0.11	BW2-BW3	0.6 -1.5	1 - 3
	Calcium phytate+lightaged	1.20	±0.08	BW2-BW3	0.6 -1.5	1 - 3

4. CONCLUSIONS

The lightfastness of a dye (colorant), like the ferrogallotannin complex in iron gall inks, is a function of the its chemical structure and physical state (particle size and distribution on the substrate). The light sensitivity properties of these five sets of iron gall inks all belong in the category of high light sensitivity (BW1-3). The inks have a very light sensitive component that results in rapid initial color change when exposed to light, follow by a slower fade. The rapid initial change in ink color is measurable by the spectrophotometer, but it may not be visibly detectable. The amount of this light-sensitive components varies with different inks. Most of the color change is a result of increase in lightness (L*) and increase in yellow (b*). Previous light exposure or aqueous treatments can reduce the light sensitivity of iron gall inks by partially breaking down or solubilizing/removing these light sensitive components. With some inks, calcium phytate treatment is able to reduce the light sensitivity more than that of calcium bicarbonate and simmering treatments. This may be due to the antioxidant properties of phytate.

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SOURCES OF MATERIALS

Bathophenanthroline Fe(II) test strips

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Diss, Norfolk

IP22 4HQ, England

Tel. +44(0) 1379 647400

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https://www2.preservationequipment.co.uk/

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University Products Of Canada

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Color charts for Fe(II) test strips

Season Tse

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1030 Innes Rd. Ottawa, ON Canada K1A0M5

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