PREDICTING THE FADING OF OBJECTS: IDENTIFICATION OF FUGITIVE COLORANTS THROUGH DIRECT NONDESTRUCTIVE LIGHTFASTNESS MEASUREMENTS

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ABSTRACT—A new approach to identifying artifacts sensitive to visible light exposure, based on the direct measurement of the lightfastness of materials that compose the object, is described. An instrument has been constructed that is capable of identifying fugitive materials (more light sensitive than Blue Wool #2) rapidly and essentially nondestructively. Accelerated light-fading tests on tiny (0.4 mm diameter) areas of an object are done while simultaneously monitoring the color change produced in the test area. The lightfastness determined in such microfading tests has been found to compare well with that measured in more conventional accelerated light-aging tests. The risks of damage to the artifacts from these microfading tests have been examined. By terminating the fading test when a small but definite color change has been produced, the risk of disfiguring the object by creating a visible bleached spot is judged to be very small. Exposure to the light intensities used in the microfading tester can heat test areas to as high as 50°C, so that low-melting materials such as waxes should be considered at risk of some degree of melting damage. For most art materials that are more heat tolerant, however, this technique holds great promise as a tool for recognizing very light-sensitive materials and for predicting the consequences of exhibition under particular lighting or atmospheric conditions.

TITRE—Prévoir l'altération des couleurs sur les objets: identification des colorants fugitifs par mesure directe et non-destructive de leur stabilité à la lumière. RÉSUMÉ—Une nouvelle approche est décrite pour identifier les objects sensibles à la lumière visible. Cette méthode est basée sur la mesure directe de la stabilité à la lumière des matériaux dont sont composés ces objets. Un appareil a été conçu qui est capable d'identifier les matériaux fugitifs (plus sensibles à la lumière qu'un étalon de laine bleue n°2) de façon rapide et essentiellement non-destructive. Des tests accélérés d'exposition à la lumière sont effectués sur des points minuscules (moins de 0.4 mm de diamètre) de la surface des objets, alors qu'on évalue simultanément l'altération des couleurs à ces endroits. La stabilité des couleurs, telle que mesurée par cette microtechnique, est comparable aux résultats obtenus lors de tests plus conventionnels. On a aussi examiné les risques de dommages causés aux objects par cette microtechnique. En terminant les tests aussitôt qu'il est possible de discerner de façon certaine la moindre altération de la couleur, le risque de créer un point de couleur plus pâle à la surface des objets devient minime. L'intensité de la lumière utilisée durant les tests peut faire monter la température des surfaces éclairées jusqu'à 50°C. Ainsi lors des tests, certains matériaux comme les cires doivent être considérés comme susceptibles aux dommages dûs à la fonte. Mais pour la plupart des autres matériaux qui résistent bien à ces températures, cette méthode offre un outil prometteur servant à identifier les matériaux très sensibles à la lumière et à prédire leurs réactions lorsqu'ils sont exposés sous certaines conditions ambiantes ou d'éclairage.

TITULO—Predicción de la decoloracion de objetos: identifcación de colorantes fugitivos a traves de medidas directas y no destructivas, de su resistencia a la luz. RESUMEN—Se describe un nuevo enfoque para identificar artefactos sensibles a la exposición a la luz visible basado en la medición directa de la resistencia de los materiales que componen el objeto a la luz. Se construyó un instrumento capaz de identificar materiales fugitivos (más sensibles a la luz que Blue Wool scale #2) rápida y esencialmente en forma no destructiva. Se efectúan ensayos de decoloración por la luz acelerados en superficies pequeñas de un objeto (0,4 mm de diámetro) mientras se monitorea

simultáneamente el cambio de color producido en el área estudiada. La resistencia a la luz determinada en dichos ensayos de microdecoloración concuerda bien con las medidas efectuadas por ensayos más convencionales de envejecimiento acelerado por efecto de la luz. Se ha examinado el riesgo de daño a los artefactos por estos ensayos de microdecoloración. Al finalizar el ensayo de pérdida de color cuando un cambio de color pequeño pero definitivo se ha producido, se considera bajo el riesgo de desfigurar el objeto creando una mancha descolorida visible. La exposición a las intensidades de luz utilizadas en el probador de microdecoloración puede calentar áreas de prueba hasta a 50°C, de manera tal que los materiales de bajo punto de fusión tales como las ceras deben ser considerados suceptivles a algún grado de daño por fusión. De todas maneras, para muchos materiales de arte que son más tolerantes al calor, esta técnica es una gran promesa como herramienta para reconocer materiales muy sensibles a la luz y para predecir las consecuencias de su exhibición bajo condiciones particulares de iluminación o atmosféricas.

1. INTRODUCTION

Light-induced fading of the colored materials on objects is widely recognized as one of the most serious threats to their preservation because of the disfiguring and usually irrevocable alteration produced. Efforts to minimize that damage are often aimed at controlling exhibition light doses by setting light intensities and display schedules so as to slow the fading of colors as much as is feasible. These efforts usually address the average needs of classes of objects—easel paintings, watercolors, woodblock prints, or dyed textiles, for example—that have come to be grouped together due to their common material types and general overall light stability.

Despite this sensible approach, some objects enter collections with unfamiliar or unrecognized materials whose light sensitivity may lie outside the norms established for a class of objects. Paintings created with synthetic organic pigments may possess unusually fugitive colorants compared to those constructed with more traditional materials. Modern works in particular may be created exclusively from materials whose light sensitivity in a gallery setting may be unknown, or they may have lower light stability by virtue of their containing materials that were never intended for continual light exposure. Similarly, objects that are to be displayed in new lighting environments—objects that have been in storage, artifacts that have been recently excavated, or even works that will be in an exhibition having lighting quite different from that in which they have heretofore been shown—may pose risks of fading damage that are difficult to anticipate.

The conventional approach to assessing this fading risk is to identify the materials that compose the artifact and to obtain a rough measure of the lightfastness through independent exposure tests of similar materials to analogous lighting. Though equipped with modern analytical tools, analysts face enormous challenges to identify colorants, particularly synthetic organic colorants, and their associated materials (binding media, mordant/fabric substrates, etc.) with the precision necessary to estimate their light sensitivity. But even if such analytical efforts were to be successful and all of the component materials could be identified, the light sensitivity of the material would still be only an estimate. It is well established that other details of the material, such as the sizes of the pigment particles, the concentration of the colorant, or the prior fading history of the material, may all be important controlling factors in its tendency to fade further (Barker et al. 1927; Cunliffe and Lambert 1932; Giles and Forrester 1980; Whitmore and Bailie 1997). As a general rule, such materials analyses are useful only for very rough estimates of lightfastness.

More recently, other approaches have been tried in order to make more precise determinations of the tendency of materials to fade from light exposure. By monitoring object colors very sensitively over time, either with color-measuring instruments or with conventional or digital photographic techniques, it is hoped that very slight color changes can be detected during the early stages of fading (Schilling 1993;

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Saunders et al. 1996). With such early detection, light sensitivities would be accurately assessed so that appropriate preservation measures could be taken. In practice, however, these techniques can be expensive and demanding in their execution, and they require diligence and equipment maintenance efforts that can tax even the most patient and dedicated staff. The most serious problem with this approach, though, is that some level of fading damage must be incurred in order to make the assessment of light sensitivity.

The method described in this article follows a different approach, one aimed at predicting an object's vulnerability by directly measuring the lightfastness of its constituent materials. A very tiny area of an object is exposed to intense light in order to induce fading, and at the same time instrumental color measurements on the illuminated area are made. By continual monitoring of the rate and extent of fading during the exposure, the light sensitivity can be rapidly assessed and the test ended before any perceptible fading has occurred on the material. With the instrument that has been constructed in this study, one can rapidly perform essentially nondestructive lightfastness determinations, and a material on an object can be identified as being fugitive (more fugitive than Blue Wool #2) after a test of only a few minutes.

2. DESIGN AND CONSTRUCTION OF FADING TESTER

2.1 DESIGN CRITERIA

In essence, the fading tester was designed to be a rapid, sensitive reflectance spectrophotometer that probes samples with light so intense it is capable of fading fugitive materials in a relatively short period of time. To make the color measurements that will indicate the degree of stability to the light exposure, a continuous spectrum of visible wavelengths of light (400–700 nm) was needed, and this necessitated the use of a source that is capable of producing this output, such as an incandescent lamp or certain types of arc lamp. This range of wavelengths also happens to be the spectral region that is most appropriate to assess fading damage as well. Not only are exhibition environments in museum galleries relatively free of ultraviolet and infrared wavelengths, but fugitive colorants, which are the materials this device is designed to detect, also have been found to be faded predominantly by visible wavelengths (McLaren 1956).

In addition to specifying the appropriate spectrum of light, two other factors were considered in choosing the light source for this device. First, the color temperature of the source, or the relative amounts of the different colors in the spectrum, had to be selected. Sunlight or artificial sources of high color temperature are common in galleries, and consequently a high-color-temperature xenon arc lamp was chosen, with the appropriate optical filters used to restrict the output to visible wavelengths only. Other sources, or other suitable optical filters on the xenon source, may be utilized to test colors exposed to other lighting environments. Second, in order to sensitively detect very slight color changes due to fading, this device needed a source with a very stable light intensity so that the measured reflected intensities (and thus the color) would not seem to change simply from fluctuations of the source intensity. This aim was accomplished by the conventional method of a light sensor that adjusts the power supply of the lamp to maintain a constant intensity. An added advantage of maintaining strictly controlled light intensities was that light doses could easily be calculated by time of exposure, thus avoiding the need for continuous intensity monitoring, integrating dosimeters, or other methods for determining total light doses.

The spectral analysis of the light reflected from the sample was achieved with a detector based on a photodiode array (PDA), a solid-state component that accumulates the intensities across the entire spectrum of wavelengths simultaneously. Such devices are becoming more common in modern spectrophotometers, and the photodiode array was preferred over the analogous charge-coupled detectors (CCD) because of its superior stability and ability to monitor relatively high light intensities. Because the entire spectrum is collected at once and very rapidly (less

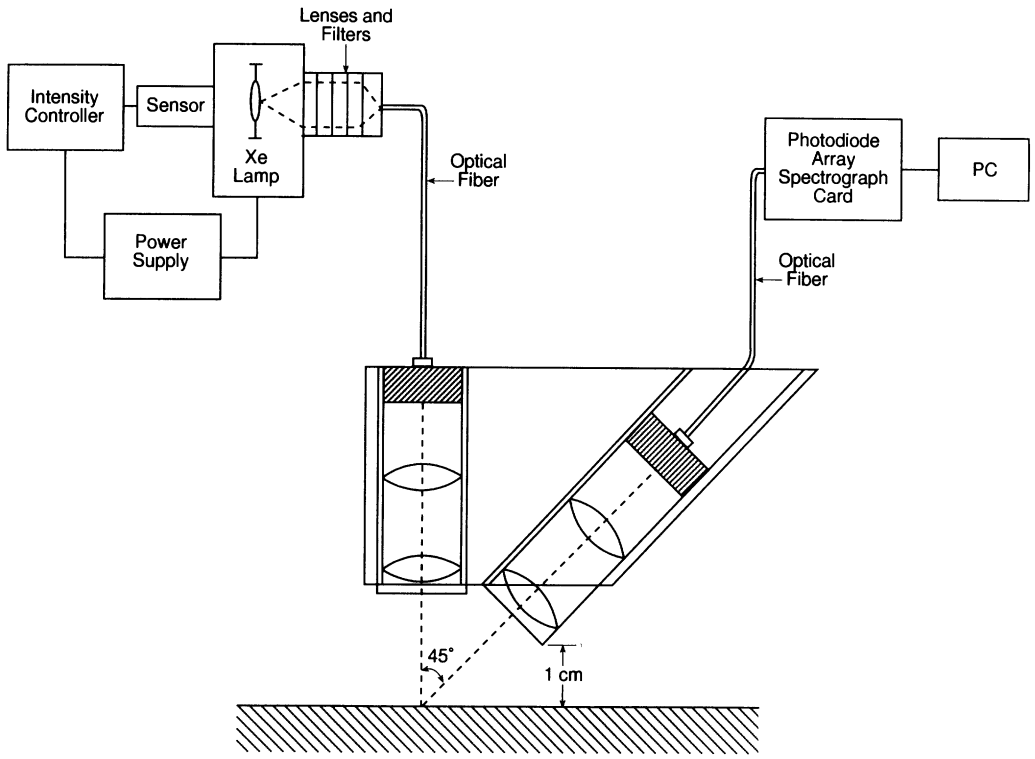

Fig. 1. Schematic of the microfading tester

than 1 second), the spectral measurements and the calculations of color parameters and color differences can occur in essentially real time as the fading test proceeds. The sensitivity to very small color changes and the ability to monitor the color change as it occurs make it possible for the lightfastness of the material to be determined rapidly and for the test to be terminated before visually perceptible fading has been produced at the test area.

The last key component of the instrument design was the method by which the light is delivered to and collected from the test material. For convenience and the safety of the artifact, fiber-optic light guides were selected for both these tasks. As has been found in museum illumination applications, fiber optics provide ease of mobility, so that the positioning at a test area and adjustments to focus the light can be made without moving either the light source or the artifact. This arrangement also allows convenient optical filtering of the light (to remove ultraviolet and infrared wavelengths, in this case) before it enters the fiber. Lenses were used to focus the light beam onto the test area and to collect a portion of the reflected light for analysis by the detector. These lenses were chosen to probe and analyze very small areas of the object and to allow a reasonable working distance, so that the surface of the artifact would not be contacted by the device. The two fibers (illumination and collection) were designed to be held in a 0°/45° geometry, with the illumination beam oriented normal to the test surface and the reflected light gathered at 45° from the normal. This configuration allows for analysis of the diffusely reflected light from the sample, which contains the information about the color of the sample.

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2.2 INSTRUMENT CONSTRUCTION AND OPERATION

A diagram of the microfading tester is shown in figure 1. A 75-watt xenon short arc lamp was used with a rear reflector assembly inside the lamp housing to increase the light output. A light-intensity controller monitored the lamp output with a sensor and adjusted the power supply to maintain the output at a preset level. Ultraviolet and infrared wavelengths were removed with a UV filter, a water filter, and a hot mirror, so that only visible light between 400 nm and 700 nm was then focused onto the end of a 200 μm diameter silica optical fiber.

The reflection fixture was a custom-machined aluminum block that held the lens assemblies for the illumination and collection fibers, with the former focusing the light perpendicularly on the sample surface and the latter collecting light reflected from the test area at 45° from normal. Both assemblies have a focal length of 25 mm and a magnification of 1.3x, and they were positioned in the holder so that their focal points coincided. Because of the protrusion of the collection lens holder, the working distance to the sample surface was about 1 cm. The aluminum holder was mounted to a translation stage that enabled adjustment of the distance from the sample surface for optimal focus and collection efficiency. The collected reflection from the sample was transmitted to the detector via a 600 μm diameter optical fiber.

The detector chosen was a fiber-optic-based spectrophotometer, utilizing a photodiode array (PDA) that has a spectral range from 375 nm to 900 nm in an array of 512 detecting elements. The solid-state spectrophotometer has no moving parts and is mounted with its associated electronics on a circuit board that plugs into an expansion slot in a personal computer. Software provided with the device controls the spectrophotometer settings, and the spectra and the calculated color parameters and color changes are displayed on the computer monitor and stored periodically on the disk. At the light intensities used, spectra were collected after every 6 milliseconds, and ten of these were averaged. These averaged spectra had less noise and were displayed and used for color calculations. In this study, color differences ΔE were calculated using the CIE 1976 $L^*a^*b^*$ equation for 2° standard observer and standard illuminant C. During a fading test, spectra and associated color information were stored in data files once every minute.

To perform a fading test, the lamp and associated optical elements were adjusted to maximize the light intensity exiting the illumination fiber, as measured with a radiometer. The aluminum holder was then positioned so as to direct the light at a white reflectance standard (barium sulfate), and the reflected intensities as observed on the computer screen were maximized by adjusting the position of the holder with the translation stage. With the shutter on the lamp-focusing assembly closed, a spectrum was collected for use as a "zero reflectance" baseline, and after opening the shutter a "100% reflectance" spectrum was collected from the white tile. The fading tester was then directed at the object to be tested. As before, the translation stage was adjusted so as to produce the maximum reflected intensities. The software was then directed to use the current color parameters for all subsequent color difference calculations, and the fading evaluation was begun. The reflectance spectrum and color difference were displayed on the screen and observed for evidence of a steady increase in the color difference. When a convincing result had been obtained, the exposure was terminated. Typically, tests were concomitantly performed on Blue Wool cloths to determine that the instrument was functioning properly and to assess the fading rate of fugitive standard materials under the current instrument conditions. Tests were usually repeated in different areas on a sample so that the overall average fading behavior could be determined from the norm of the various microfading test results. Since the spectra collected during the test and the calculated color data were all stored in computer files on the hard disk, it was possible to re-examine the test results, ensuring that the spectral changes were consistent with fading, and to construct plots of the fading test

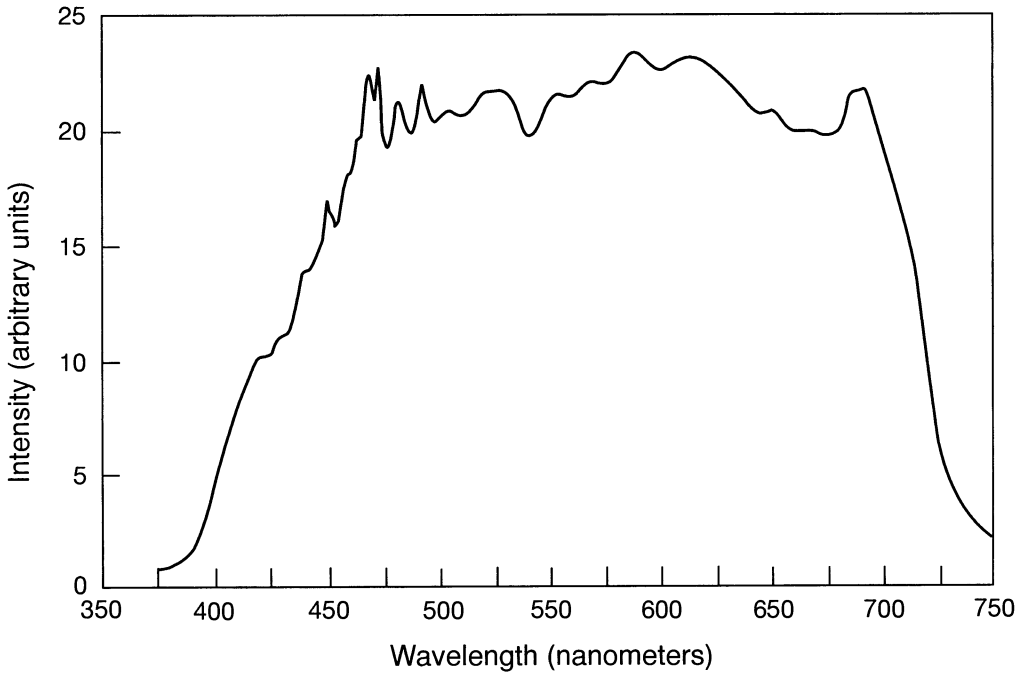

Fig. 2. Spectrum of illumination used for the microfading tests

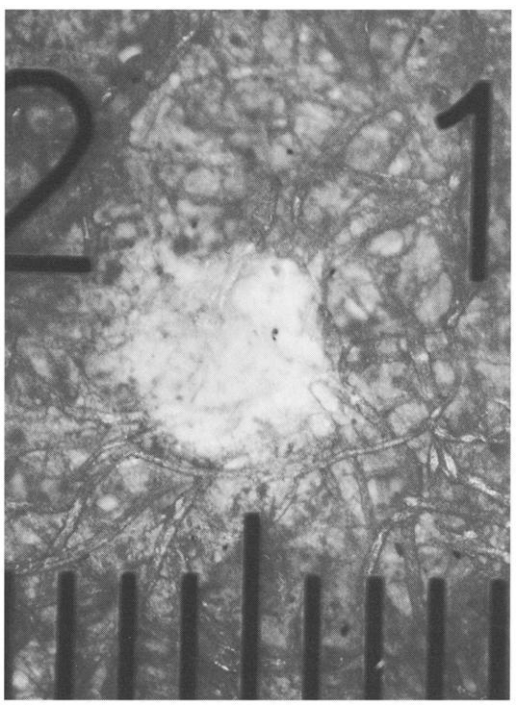

Fig. 3. Photomicrograph of a bleached test area. Each tick mark represents 0.1 mm. The microfading test was prolonged to produce the perceptibly faded test area.

results (such as ΔE versus time) in a spreadsheet program.

3. RESULTS

3.1 PERFORMANCE CHARACTERISTICS

The spectrum of incident light at the sample is shown in figure 2. From the photomicrograph of a bleached test area shown in figure 3, the approximate size of the test area can be seen to be no more than about 0.4 mm in diameter.[1] With the lamp operating at 75 watts, the luminous flux of the incident light can reach as high as 0.95 lumen (7.6×10^6 lux for a 0.4 mm diameter spot). While the intensity controller maintains a constant intensity during the course of several fading tests, over the 400-hour life of the lamp the average intensity declines steadily from the maximum value obtained with a new lamp. Thus fading tests performed with a new lamp and with an older lamp will have been done at different intensities. For this reason, microfading tests of standard Blue Wool cloths, or any other standard material, should be done in order to determine the fading rates relative to

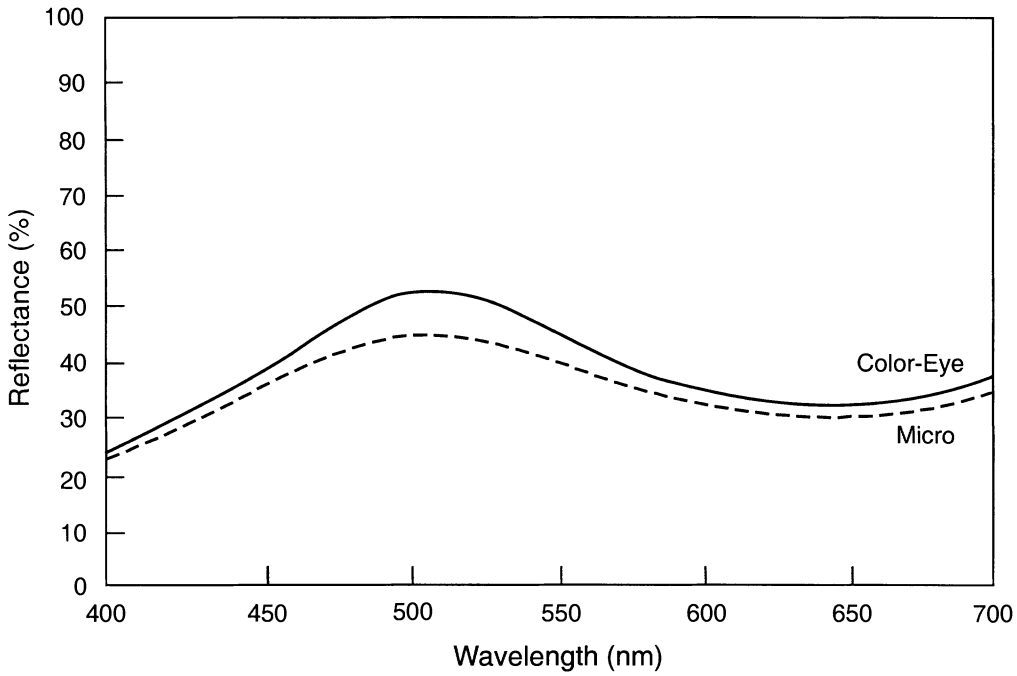

Fig. 4. Reflectance spectrum of a standard green tile measured with the microfading tester and with a conventional spectrophotometer (Macbeth Color-Eye 7000)

these standards at the current lamp intensity. The test area is not illuminated with perfectly uniform light intensity, and from observations of the size of faded spots during a test, it seems that the central 0.2 mm area is exposed to a somewhat higher intensity than the outer edges of the test area. This uneven illumination makes precise calculations of light intensities and doses in the test area difficult, although it is nevertheless useful to estimate an approximate equivalent dose under ambient intensities. But because the objective of the microfading test is the determination of the relative fading rate of an unknown material versus a standard material (such as a Blue Wool) under the same conditions, the validity of the test should not be affected by small nonuniformities in light intensity over the test areas.

The reflectance spectrum measured with the microfading tester is very similar to that obtained with a conventional spectrophotometer that samples a much larger area, as can be seen in the spectrum of a standard tile shown in figure 4. The reason for the difference between the measurements by the two instruments is unclear, although differing illumination and collection geometries are expected to contribute to the discrepancy. Nevertheless, the reflectance spectra measured with the microfading tester are reasonably accurate across the spectrum, and they are also quite reproducible and precise, with overall instrumental drift accounting for a ΔE value of less than 0.2 per hour. For a typical fading test, which takes less than 1 hour, this stability should be sufficient for reasonably sensitive determinations of color changes from fading, so that color changes to a level of $\Delta E = 5$ or so should be considered definite.

Microfading tests were performed on standard Blue Wool cloths in order to determine how quickly this level of color change might be produced in relatively fugitive materials exposed to these light intensities. The results for Blue Wools #1 and #2 are shown in figure 5. At the light intensities reached in this device, Blue Wool #1 faded to a $\Delta E = 5$ in about 4 minutes, and Blue Wool #2 reached that level in about twice that long. This finding indicates that materials whose light sensitivity is equivalent to or greater than a Blue Wool #2 can be identified as such in a microfading test of less than about 10 minutes.[2]

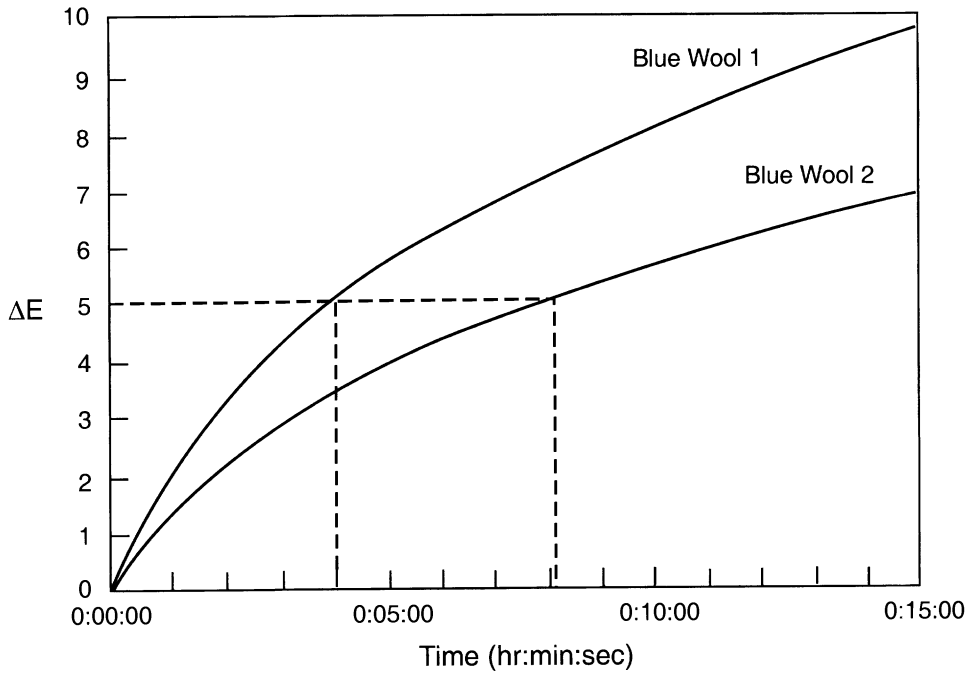

Fig. 5. Microfading test results for standard Blue Wool cloths #1 and #2

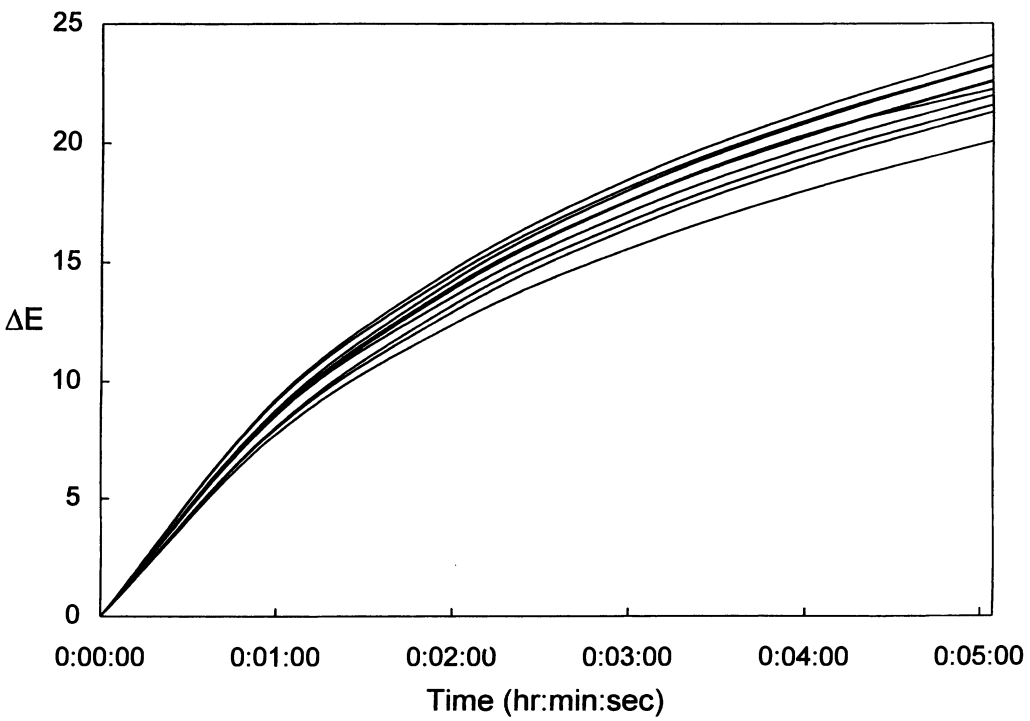

Fig. 6. Results of microfading tests on 10 areas of a sample of Winsor & Newton Bengal Rose gouache on paper

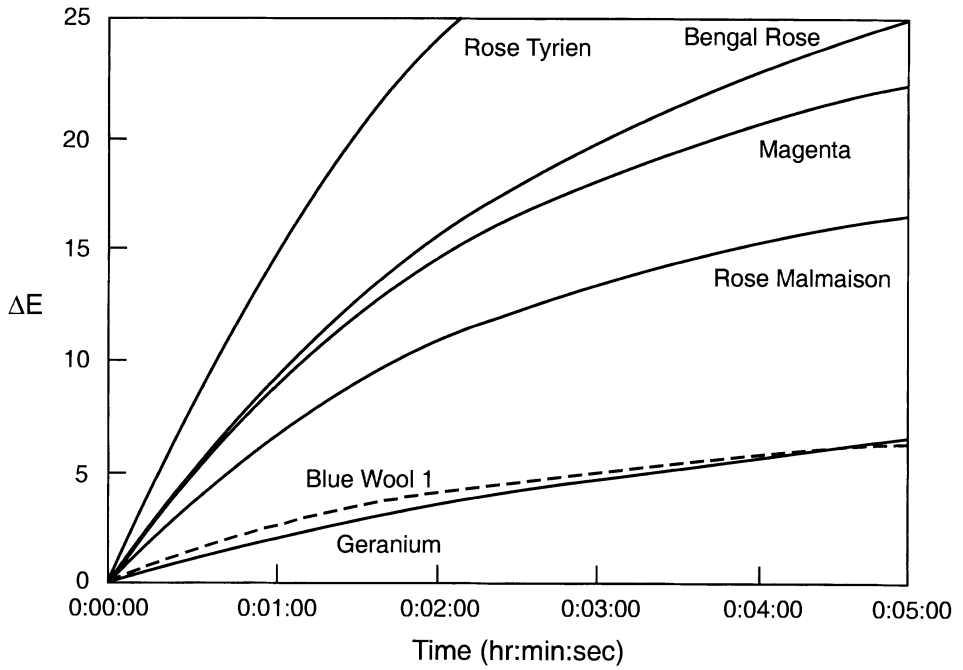

Fig. 7. Microfading test results for fugitive Winsor & Newton gouaches

This rapid screening allows multiple tests to be done on a given material to ensure that the fading of a very tiny test area accurately represents the average light sensitivity overall.[3] Test results on a relatively uniform gouache sample on paper show the good precision of the microfading test results, which allows a reasonable determination of the light sensitivity of the overall material (fig. 6). And, of course, the speed with which such microfading surveys may be done allows the screening of many colored areas on a single object during the course of an examination.

3.2 FADING TEST RESULTS FOR TYPICAL ART MATERIALS

Microfading tests were performed on a variety of art materials in order to assess the range of lightfastness that might be encountered in artifacts made with readily available, albeit not necessarily fine-art–grade, materials. Illustration-grade gouache paints, school-grade poster paints, felt-tipped markers, inks, and colored construction papers were all screened and compared to Blue Wool cloths that were also tested. Not surprisingly, many materials were found to be fugitive (less lightfast than Blue Wool #2), some even much more fugitive than Blue Wool #1. The microfading test results for some fugitive gouache paints (Winsor & Newton gouaches Rose Tyrien, Bengal Rose, Magenta, Rose Malmaison, and Geranium) are shown in figure 7. For these tests, the samples were exposed for 9 minutes to 6.4 x 10^6 lux (calculated for an illuminated spot 0.4 mm in diameter), giving a total light dose of 0.96 x 10^6 lux-hours. This light dose is equivalent to about 7 years in a museum gallery illuminated at 50 lux (8 hours of light exposure per day).

3.3 COMPARISON TO CONVENTIONAL FADING TESTS

In order to assess the accuracy of the fading results obtained in the microfading test, microfading and conventional fading tests (in a table-top xenon arc exposure cabinet, with color measurements from a reflectance spectrophotometer) at the same light dose were performed on the same samples. (For

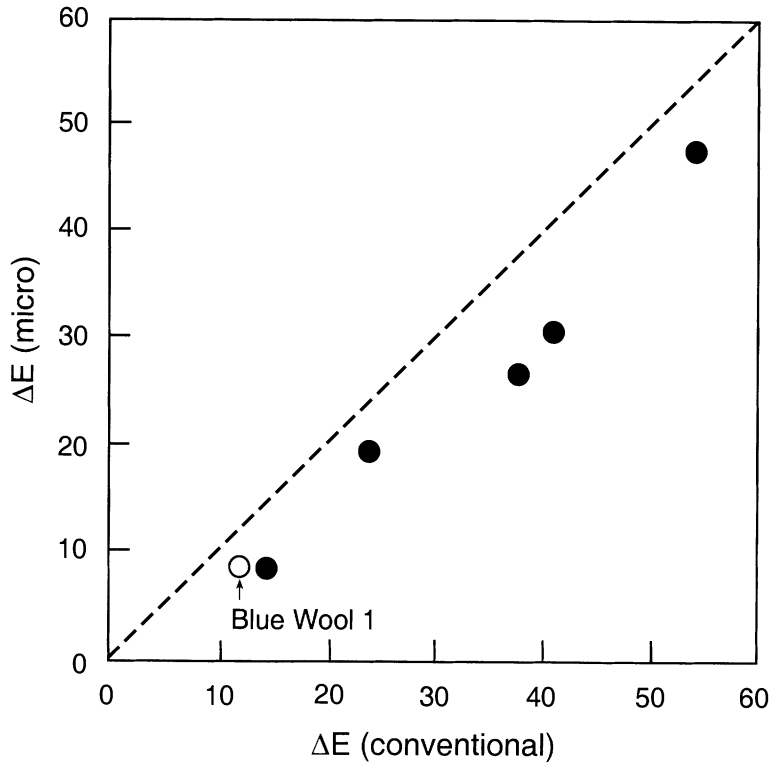

Fig. 8. Color change produced in microfading and conventional fading tests for fugitive Winsor & Newton gouaches (the same as those shown in figure 7) and standard Blue Wool #1, after a total light dose of 0.94 x 10^6 lux-hours

details on typical procedures for performing these conventional tests, see, for example, Whitmore and Bailie 1997.) Figure 8 shows the color changes measured with the microfading tester and with the conventional spectrophotometer following the exposures in each of the two tests. (Note that these tests were done so as to produce very large color changes for easier comparison.) Evidently the microfading tester tends to produce color changes slightly smaller than those measured in the conventional fading test. Whether there are real differences in the fading produced in the samples or simply discrepancies in the reflectance spectra measured in the two devices is not known, but both probably contribute. Nonetheless, the ΔE values obtained with the two instruments are quite similar, and the relative lightfastness rankings of the samples are the same. This comparison establishes the feasibility of this microscale fading technique and suggests that, for the samples tested here, reciprocity (the validity of the results for predicting fading at ambient light intensities) holds as well for the microfading test as for the conventional accelerated lightfastness test.

4. SAFETY EVALUATION

The choice of the level of color change that is to be considered a definite endpoint to the test is a rather arbitrary one, selected to be large enough to be easily measurable by the device but not so large as to produce a visibly bleached test area. With the stability and sensitivity of this instrument, even the very small color change of ΔE = 5 is easily measurable. In observing large uniform samples under ideal conditions, one may be able to just perceive an overall color change of this magnitude. But microscopic test

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areas faded to this slight degree remained visually unaltered, even in very uniform applications of color. Faded test areas were only perceptible when the tests were extended to produce ΔEs of about 15 or greater, and even then the altered areas were no larger than those produced by removing material for a pigment or medium analysis. In order to determine whether the test areas would eventually become visible at a later time, samples that had undergone microfading tests to $\Delta E = 5$ were subsequently faded either in accelerated xenon exposure tests or in ambient lighting, and in none of the samples did the test areas ever become perceptible. The chemical changes produced in the microfading test are evidently too slight to produce significant differences in color between the test area and its surrounding area. For test areas where the color changes are only $\Delta E = 5$, the risk of disfiguring the object as a result of the test is judged to be minimal. Where concerns remain, one can still choose to perform the microfading test in areas that are suited for removing samples for analysis: at damages, at edges of paintings, at the boundaries between color areas, or in areas where the color is already very nonuniform. Fading tests at other sites, such as in areas hidden by a frame rabbet, on tacking margins, or in other obscured locations, may not yield the relevant information about the light sensitivity of materials in the exposed areas.

While the risk of disfiguring an object from producing a perceptibly faded test area was judged to be very small, another important concern was the risk of damage due to heating from the intense incident light. The temperature of the sample surface in the test area was measured in two ways, one a direct measurement with a thermocouple and the other by observation of melting damage to wax crayons having well-defined melting temperatures. In the first method, a miniature K-type thermocouple junction (a welded connection between wires of chromel and alumel) 0.04 mm in diameter (about 1/10 the size of the illuminated spot) was adhered to a piece of watercolor paper with a very thin layer of oil paint, and after allowing the paint to dry for about a week, the light was focused onto the junction. Paints of various colors (Mars Black, Phthalocyanine Green, French Ultramarine Blue, and Alizarin Crimson) were used in order to probe the heating for samples of varying degrees of light absorption. At 6.4×10^6 lux (the same light intensity as in the fading tests) the maximum temperature observed was 44°C, with Phthalocyanine Green paint. In the second temperature test, marks were made with the temperature-indicating wax crayons on the surface of watercolor paper painted with the above oil colors. Light from the microfading tester was then focused on these marks, and any resultant melting damage was observed with the aid of a microscope. By this method a maximum temperature of 48°C to 52°C was observed, again on the sample of Phthalocyanine Green oil paint.

These maximum temperatures are approximately the same as those produced on samples tested in outdoor exposures, and they fall at the lower end of the temperature range encountered on samples exposed in commercial xenon arc test cabinets, typically 50°–70°C depending on the sample color and ambient conditions in the chamber (Fischer and Ketola 1994). This degree of sample heating in the microfading test area is not unexpected, since the light intensities in the microfading tester are on a par with those used in the commercial test cabinets. With this modest heating, most objects are unlikely to sustain any damage, and only those very low-melting materials such as some wax media might be at risk. A reasonable rule of thumb might be to consider the risk of heat damage significant for materials that would not survive hot table treatments or hot summer days outdoors.

5. OTHER APPLICATIONS

The most obvious application of the microfading tester is the identification of fugitive colors on artifacts that will allow more informed decisions about preserving them. The identification of such extremely light-sensitive colors might also prove useful in another context, though, such as predicting the longevity of a good color match for a retouching

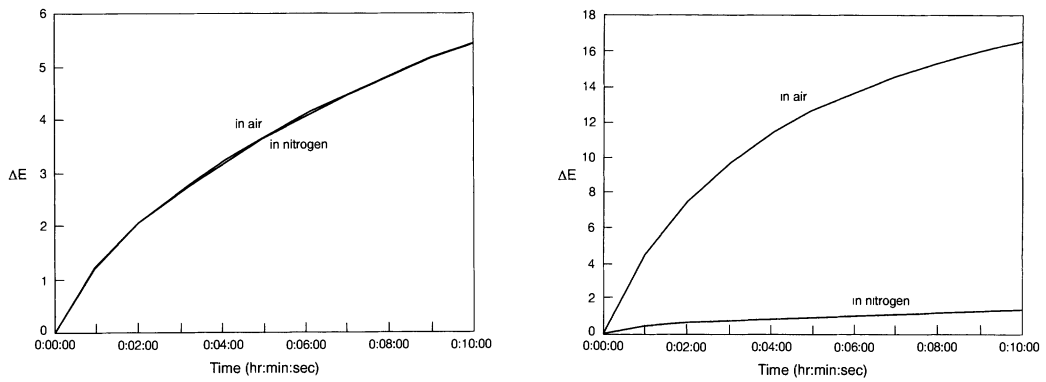

Fig. 9. Microfading test results in air and in nitrogen for: (a) standard Blue Wool #1, and (b) Winsor & Newton Rose Malmaison gouache on paper

used to repair a fugitive original color. Retouching would normally be done with lightfast colorants, and although the color match to an original may be good at first, subsequent fading of very fugitive original colors adjacent to the repair would soon make the inpainting conspicuous. Recognition of the light sensitivity of the original paint through a microfading test would demonstrate not only a need for special care to preserve the original, but also the need to retard fading that might cause a repair to rapidly become visually obtrusive.

A more critical application of microfading tests is in exploring the efficacy of preservation measures designed to protect colors known to be very light sensitive. Many light-fading reactions require atmospheric oxygen, and preservation steps such as housing in oxygen-free atmospheres are sensible yet generally expensive strategies to protect these objects. However, some fading reactions may still take place without available oxygen, and it is currently extremely difficult to predict the benefits that are to be realized from affording a particular object this special housing.

The microfading tester is particularly well suited for rapidly determining the effect of such a measure before one has undertaken the construction of such an enclosure. By tenting the art object and the aluminum lens holder of the fading tester in plastic sheet (passing the fiber optics through the plastic tent), and then performing microfading tests in air and after flushing the tent with nitrogen, one can measure the extent to which the light sensitivity is changed in the new environment. Figure 9 shows the results obtained for two samples, one the standard Blue Wool #1, which remained just as fugitive in an oxygen-free enclosure as in air, and the other a fugitive gouache, whose lightfastness was increased dramatically in an oxygen-free housing. Such information would be extremely valuable when these expensive preservation measures are first being considered.

6. CONCLUSIONS

This article presents a new approach to identifying artifacts whose colors are sensitive to visible light exposure, based on the direct measurement of the lightfastness of the materials that compose the object. The instrument described here has been shown to be capable of identifying fugitive materials (more light sensitive than Blue Wool #2) rapidly and essentially nondestructively, so that even conspicuous image areas on objects can be evaluated before unanticipated fading damage has been incurred. The risks of damage to the artifacts from these microfading tests have been examined. By terminating the fading test when a small but definite color change has been pro-

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duced, the risk of disfiguring the object by creating a visible bleached spot is judged to be very small. Exposure to the light intensities used in the microfading tester can heat test areas to as high as 50°C, so that low-melting materials such as waxes should be considered at risk of some degree of melting damage. For most art materials that are more heat tolerant, however, this technique holds great promise as a tool for recognizing very light-sensitive materials and for predicting the consequences of exhibition under particular lighting or atmospheric conditions.

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NOTES

1. In this photomicrograph, the test area was intentionally bleached to a degree great enough that the spot was made visible. A typical microfading test would, of course, be terminated before such large color changes had occurred.

2. While it is attractive to consider extending the usefulness of this device to probe more lightfast materials, equivalent to Blue Wool #3 or higher, the use of strictly visible wavelengths makes fading of lightfast materials, which react very little to visible light, essentially unfeasible with the device in its current design: the microfading tests can take many hours to produce any significant color changes in lightfast materials. Inclusion of ultraviolet wavelengths in the illumination is straightforward, and the device has been used successfully to test the fading of more-lightfast materials from ultraviolet light exposure. However, a number of design changes, particularly to reduce chromatic aberrations in the optical components, would be necessary for the illumination from the fiber to have the proper proportion of UV and visible light for correct solar simulation.

3. Of course, for materials that are not uniformly colored on this size scale, such as poorly blended paints or dot-matrix prints, the microfading test result cannot be immediately translated into the appearance change of the additive color mixture. Nevertheless, the presence of fugitive colorants in such materials is an unambiguous determination.

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SOURCES OF MATERIALS

Light source (75 W xenon lamp, cat. no. 6251; lamp housing, cat. no. 6000; arc lamp interface kit, cat. no. 60010; socket adapter, cat. no. 60014; condensing lens assembly, cat. no. 60006; filter holder, cat. no. 62020; fiber focusing assembly, cat. no. 77800; rear reflector assembly, cat. no. 60005; universal power supply, cat. no. 68805; ignitor, cat. no. 68705; intensity control system, cat. no. 68850; adapter for lamp housing, cat. no. 68856); filters (long pass UV filter, cat. no. 59470; water filter, cat. no. 61945); test head lens assemblies (focusing beam probe, cat. no. 77646; 25 mm focal-length lens, cat. no. 41220); optical fibers (1 m long, 200 μm and 600 μm fused silica UV-Vis fiber with SMA connectors)
Oriel Corporation
250 Long Beach Blvd.
P.O. Box 872
Stratford, Conn. 06497

Hot mirror
ZC&R Coatings for Optics
1250 East 223d St., Suite 111
Carson, Calif. 90745

Translation stage (cat. no. 3682)
Edmund Scientific Company
Industrial Optics Division
101 East Gloucester Pike
Barrington, N.J. 08007

Photodiode array spectrograph card (Model CDIP-DA/360-900/1.2) and software
Control Development
3702 West Sample St.
South Bend, Ind. 46619

Thermocouple (cat. no. CHAL-0005) and temperature-indicating crayons (cat. nos. STK-0109, STK-0113, STK-0119, STK-0125, STK-0131)
Omega Engineering
One Omega Dr., Box 4047
Stamford, Conn. 06907

Thermocouple controller (Digi-Sense, Model 8528-20)
Cole-Parmer Instrument Co.
625 East Bunker Ct.
Vernon Hills, Ill. 60061-1844

Radiometer (Model IL1700)
International Light
17 Graf Rd.
Newburyport, Mass. 01950

Light exposure apparatus (Suntest CPS)
Atlas Electric Devices Co.
4114 N. Ravenswood Ave.
Chicago, Ill. 60613

Spectrophotometer (Color-Eye Model 7000) and standard color tiles
Macbeth Division
Kollmorgen Instruments Corp.
405 Little Britain Rd.
New Windsor, N.Y. 12553

Blue Wool reference cards
Talas
568 Broadway
New York, N.Y. 10012

Art supplies: Various retail outlets

PREDICTING THE FADING OF OBJECTS: IDENTIFICATION OF FUGITIVE COLORANTS THROUGH DIRECT NONDESTRUCTIVE LIGHTFASTNESS MEASUREMENTS

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