# ASSESSING LED LIGHTS FOR TEXTILE COLORANTS

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ABSTRACT—Museums are increasingly interested in installing energy-saving light sources, such as LED (light-emitting diode) lamps; however, LEDs are still a new technology with legitimate concerns about the effects of light spectra on artifacts, including textiles. Many models may not possess the same color-rendering properties that observers are accustomed to, and it is important to understand the effects that spectra can have on the perception of dyed textiles. This research explored the effects of different light spectra, including those of LEDs, on popular dyes with the goal of understanding the interaction of light with textiles. Eleven early synthetic dyes and two natural dyes were selected for exposure to 10 different LED spectra. This paper summarizes our findings to date: LED spectra with the same color temperature can render very different observable colors, especially with saturated colors. Saturated purples were found to be extremely hard to render accurately under LEDs. The experiment indicates that color temperature and illuminance level are no longer sufficient when specifying a light source for exhibit.

EVALUACIÓN DE LAS LUCES LED PARA LOS COLORANTES TEXTILES: RESUMEN—Cada vez más, los museos muestran su interés por instalar fuentes luminosas que ahorren energía, como lámparas LED (diodos emisores de luz). No obstante, la tecnología de las luces LED es nueva aún y despierta una preocupación legítima sobre los efectos de los espectros lumínicos en los objetos, incluyendo las telas. Muchos de los modelos tal vez no tienen la misma capacidad de representar los colores a la que los observadores están acostumbrados, y es importante entender los efectos que los diferentes espectros lumínicos pueden tener sobre la percepción de las telas teñidas. Esta investigación exploró los efectos de diferentes espectros lumínicos, incluyendo los de las luces LED, sobre las tinturas más populares con el objeto de entender la interacción de la luz con las telas. Se seleccionaron once tinturas sintéticas y dos tinturas naturales y se las expuso a 10 espectros de luces LED diferentes. Este documento resume los resultados hasta la fecha: que el espectro de las luces LED con la misma temperatura de color puede producir colores apreciables muy diferentes, especialmente con los colores saturados. Se encontró que los púrpuras saturados eran muy difíciles de apreciar con precisión bajo las luces LED. El experimento indica que la temperatura del color y el nivel de iluminación ya no son suficientes al especificar una fuente lumínica para la exhibición.

## 1. INTRODUCTION

Color and lighting of historic textiles are critical factors in visitor experience. Visitors want adequate light to perceive color well, while museums want to minimize light on artifacts to reduce actinic damage. Traditional artificial lighting sources used in museums are incandescent, including halogen, and occasionally fluorescent; however, LED lighting is quickly gaining popularity as an energy-saving option because manufacturers are now able to offer better quality assurance and color uniformity. The spectral power distribution (SPD) of LEDs can be very different from other artificial lighting sources and could significantly alter the appearance of artifacts. Although there are many studies involving the lighting of sculpture and paintings, textiles are often more susceptible to light damage and additional research is required to understand the role LEDs should have in lighting dyed textiles. Previous studies examining effects of modern light sources on historic textiles have been conducted and have proved that dyes fade differently under different spectra (Ishii et al. 2008; Commission

Internationale de L'Eclairage (CIE) 2004). In order for museums to use these options safely, a better understanding of light spectra and their effect on dye color perception and fading is required. To do this, light sensitive dyes should be observed and assessed under different LED technologies.

The Energy Independence and Security Act of 2007 introduced energy efficiency regulations for lighting that have effectively banned (after 2014) the production of incandescent lamps, excluding specialty bulbs (Energy Independence and Security Act of 2007). Incandescence in traditional lighting creates light in response to heat. With incandescent lighting becoming obsolete, the lighting industry is producing innovative lighting options using new and ever-changing technology, including LEDs. LEDs are manufactured to work by using semiconductors doped with phosphor materials. This creates an effect called electroluminescence, where light is emitted in response to an electrical current or strong electric field. The first patent for applicable LED technology was issued in 1966 (Biard and Pittman 1966) using gallium arsenide as the semiconductor. Over the last half century, semiconductors have become an important material used in many different electronics, and the market demand is driving research in the electronics and lighting industry. Although gallium arsenide remains a popular semiconductor, indium gallium nitride is more common in current cost effective LEDs on the market. Indium gallium nitride's emitted wavelength ranges from 390–440 nm depending on the material's band gap (controlled by the ratio of GaN/InN). As museums implement and install LEDs, it becomes increasingly important to understand how the spectra of these technologies affect the color rendering of historic dyed textiles.

The market for LEDs is expanding into industries where color rendering is critical. The Department of Energy (DOE) has funded the Solid-State Lighting GATEWAY Demonstrations to showcase high-performance LEDs in different applications, including museum gallery lighting (DOE 2013). GATEWAY museum demonstrations include projects with the Smithsonian American Art Museum, J. Paul Getty Museum, Jordan Schnitzer Museum of Art, and the Field Museum of Natural History. These reports focus on energy savings and feasibility of installing lamps in detail, and examine appearance of artifacts examined under LEDs; however, they did not study the effects of LEDs on fidelity in color perception of textiles. The international color organization, Commission Internationale de L'Eclairage (CIE) has released a draft of terms and definitions for lighting with inorganic semiconductors that will later be developed into a standard (CIE 2013) and a report that examines the suitability of existing lighting quality measures for interior LED lighting (Dikel et al. 2013). With increasing interest in LEDs' ability to render color, there is a need to explore and collect information about the effects of LEDs used in museums to light galleries with historic dyed textiles.

The elements that make up an LED's semiconductor material determine the color of light emitted in a manner similar to neon lighting, and there is a lot of variability between lamp models. The majority of LEDs use a semiconductor that emits a peak of blue-green light and a phosphor that luminesces a broader band of orange-yellow, which together create a white light (see fig. 1, graph E). The white light produced in this manner by LEDs is not a true white light, meaning a white light made up of nearly equal quantities of all colors of light in the visible spectrum. Although LED technology does have the capacity to create a full spectrum light source, doing so will not only increase the cost of producing the lamp but it will also sacrifice energy efficiency. Presently, LEDs are gaining interest exactly because they are a money saving option. To increase the market for LEDs, manufactures are trying to decrease the cost of lamps, which further limits the materials that are used, and the range and energy of colors emitted. Color rendering is not critical in many of their applications (e.g., automotive headlamps). Since LEDs are still a new technology and many models may not possess the same color rendering properties that observers are used to within the tradition of incandescent lamps, it is important to understand the effects that spectra can have on the perception of dyed textiles.

In this research three questions are examined. The first question is whether LED lighting will change color rendering uniformly by affecting all colors equally or change color rendering by groups of color. Uniformly changing the colors would affect the tonality but not their harmony; however, if different hues at different chroma are not equally affected, the color rendering of the textile may be skewed, depending on the particular colorway. The second question is whether the existing descriptors used to differentiate or grade LEDs are adequate for purposes of dyed textile display. The color rendering index (CRI) measures the ability of light sources to illuminate objects faithfully in comparison to an ideal or natural light source (usually incandescent). Another descriptor often used is Correlated Color Temperature (CCT) for the apparent color of a source warmer or cooler in color tone, meaning closer to incandescent light or to daylight, respectively. The third question is whether SPD as described by its manufacturer can be used to predict color rendering. Nanometer by nanometer across the 400–700-nm visible spectrum, the LEDs can be engineered to have specific levels of energy. The SPD of LEDs can vary from other artificial lighting sources and could significantly alter the appearance of artifacts.

## 2. MATERIALS AND EXPERIMENTAL METHOD

### 2.1 MATERIALS

Cotton and silk selected for dyeing were bleached desized cotton (style 400) and silk broadcloth (style 607) from Testfabrics, Inc. They possess similar fabric weight and construction to each other, which reduces variation in color readings (table 1).

Table 1: Fabrics Used in Study

| Fiber | Testfabrics, Inc. Style # | Fabric Weight (g/m$^2$) | Weave Construction | Fiber Density (g/cm$^3$) |
|---|---|---|---|---|
| Cotton | 400 | 100 | Plain | 1.55 |
| Silk | 607 | 105 | Plain | 1.30 |

Dyes selected for the study included 11 early synthetic dyes and 2 natural dyes. These dyes were selected for their known poor light fastness and range of colors (table 2).

Table 2: Dyes Used in Study

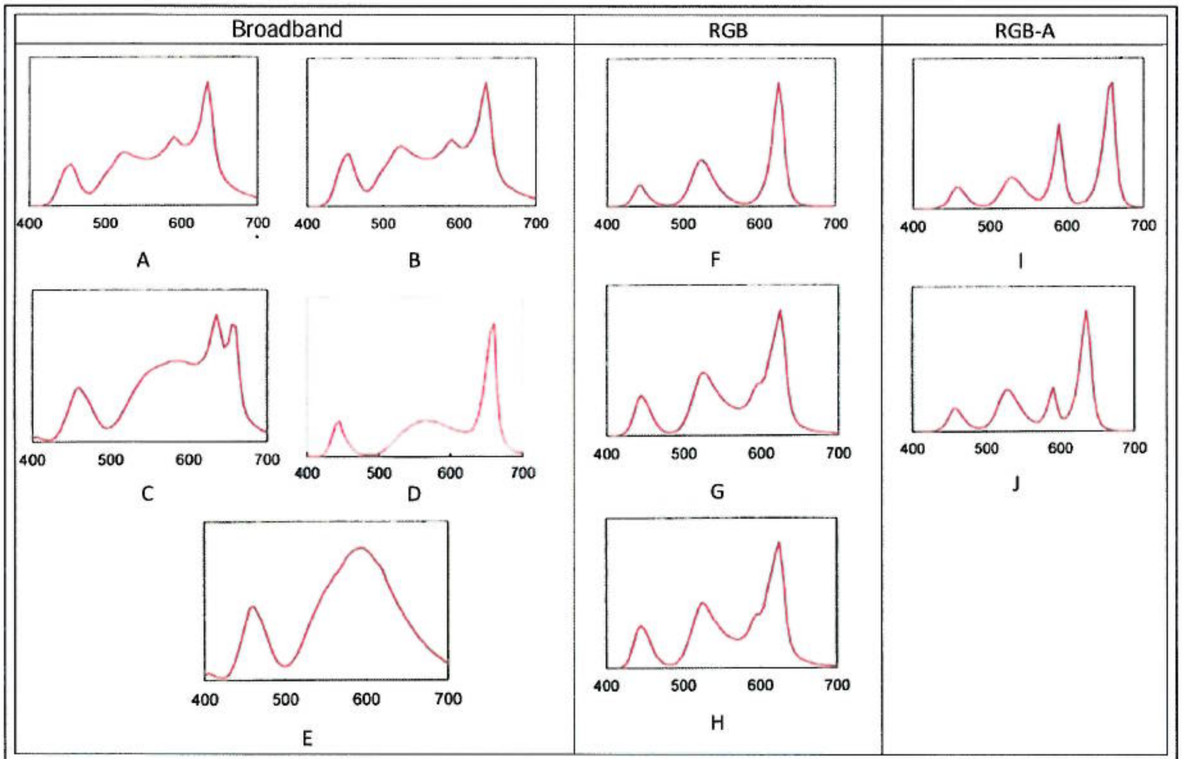
| Dyestuff | C.I. Name | C.I. Number |
|---|---|---|
| Napthol Yellow | Acid Yellow 1 | 10316 |
| Uranine A | Acid Yellow 73 | 45350 |
| Auramine | Basic Yellow 2 | 41000 |
| Chrysoidine | Basic Orange 2 | 11270 |
| Crystal Violet | Basic Violet 3 | 42555 |
| Diamond Green B | Basic Green 4 | 42000 |
| Magenta | Basic Violet 14 | 42510 |
| Rhodamine 6G | Basic Red 1 | 45160 |
| Vesuvin BA | Basic Brown 1 | 21000 |
| Victoria Blue B | Basic Blue 26 | 44045 |
| Congo Red | Direct Red 28 | 22100 |
| Safflower | Natural Red 26 | 75140 |
| Turmeric | Natural Yellow 3 | 75300 |

### 2.2 SAMPLE PREPARATION

Cotton and silk fabrics were cut into samples that weighed approximately 20 g each and the weight, to four decimal places, was recorded. Each of the 11 synthetic dyes was dissolved into deionized water at 1% by weight (e.g., 1 g of dyestuff per 100 mL of deionized water). Each sample was separately dyed with the appropriate mordant and dwell time (Schweppe 1986) and/or auxiliaries (Schweppe 1987) using a 1:50 dye bath liquor ratio.

### 2.3 LIGHT EXPOSURE

Ten unique SPDs with different attributes were created using spectrally tunable lighting facility at the National Institute of Standards (NIST) with the assistance of Dr. Yoshi Ohno (fig. 1). The SPDs represented three different types of LED models: RGB, RGB-A, and broadband. The SPDs were mostly 3000°K and viewed at 100 lux.



A m-CB_3000K broadband LED with peak at 455nm
B m-CB_3500K broadband LED with peak at 455nm
C m-CB_3000K blue phosphor_CRI 85
D m-CB_YAG white 3000K, 100 lux
E m-CB_3000K blue phosphor_CRI 67
F m-CB_3 Peak_RGB_CRI 37
G m-CB_3 Peak_RGB_CRI 85
H m-CB_3 Peak_RGB_CRI 85, 40 lux
I m-CB_4 Peak_3000K, 100 lux B
J m-CB_4 Peak_3000K, 100 lux A

Figure 1: Spectral power distributions of LED spectra created at NIST. The visible spectrum is measured in nanometers (abscissa) and the energy (ordinate) present at each nanometer is relative.

## 2.4 EVALUATION METHODS

Each sample was measured for color-rendering changes under different spectra using the spectrally tunable lighting facility at NIST, where it is possible to switch rapidly between spectra. A digital simulator program with the spectral reflectance data for the fabric samples and the spectral emittance information for the LEDs was used for comparison and tracking color change using ΔE (See equation 1 for formula used). This simulator (Davis and Ohno 2011) is available for download free of charge from the NIST website.

$$\Delta E = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2}$$

Equation 1: Formula used for Delta-E calculation

Finally a Canon PowerShot ELPH-150 12 megapixel point-and-shoot camera was used to photograph and record videos of the samples with the existing (changing) light sources. These photographs and videos give a general idea of the color change seen, but may not be completely accurate in portraying the change seen in person.

## 3. RESULTS AND DISCUSSION

In this research we used light with 10 unique SPDs to approximate the effect of different LED lights on color rendering of 11 dyes on two textiles. By comparing human perception, digital photography, and digital color prediction simulations, it was possible to gauge how useful the simulator program was in estimating the difference in color rendering. It was determined that the program's digital rendering was accurate for predicting the suitability of a source to be used with textiles for color rendering purposes. For example, the same crystal violet sample (reflectance data for this sample was collected with a Hunter MiniScan EZ and is shown in fig. 2) was examined under two LED lights with the same color temperature, but different SPDs (fig. 3). The first LED has a peak around 660 nm (red region) making the sample appear redder, while the second LED does not have any strong red peaks making the sample appear bluer. Purple is unique in reflecting high energy (blue) and low energy (red) visible light, and, therefore, is difficult to render accurately under

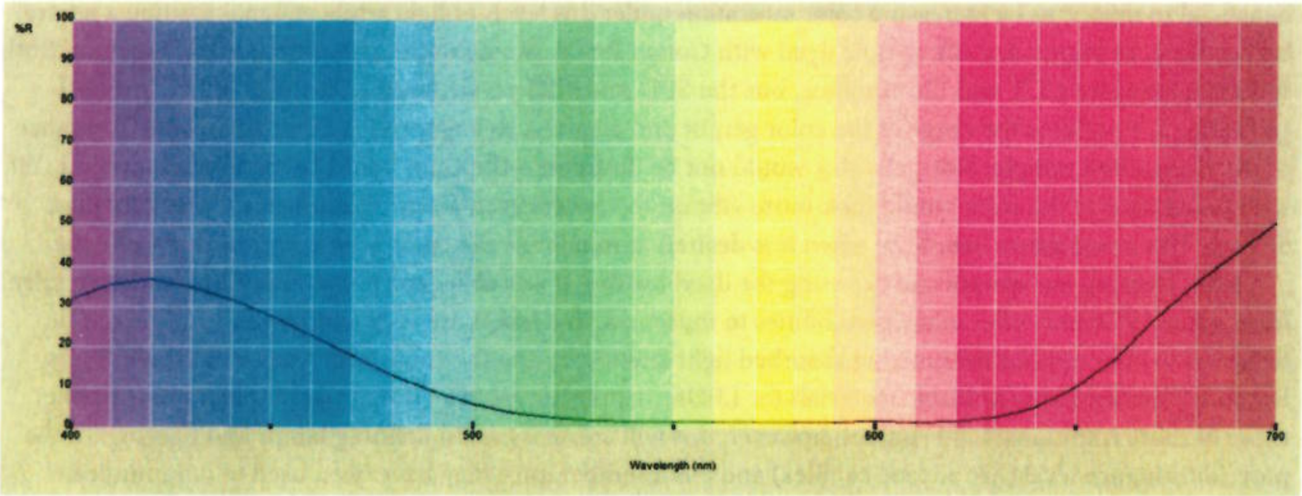


Figure 2: Reflectance data for Crystal Violet on silk

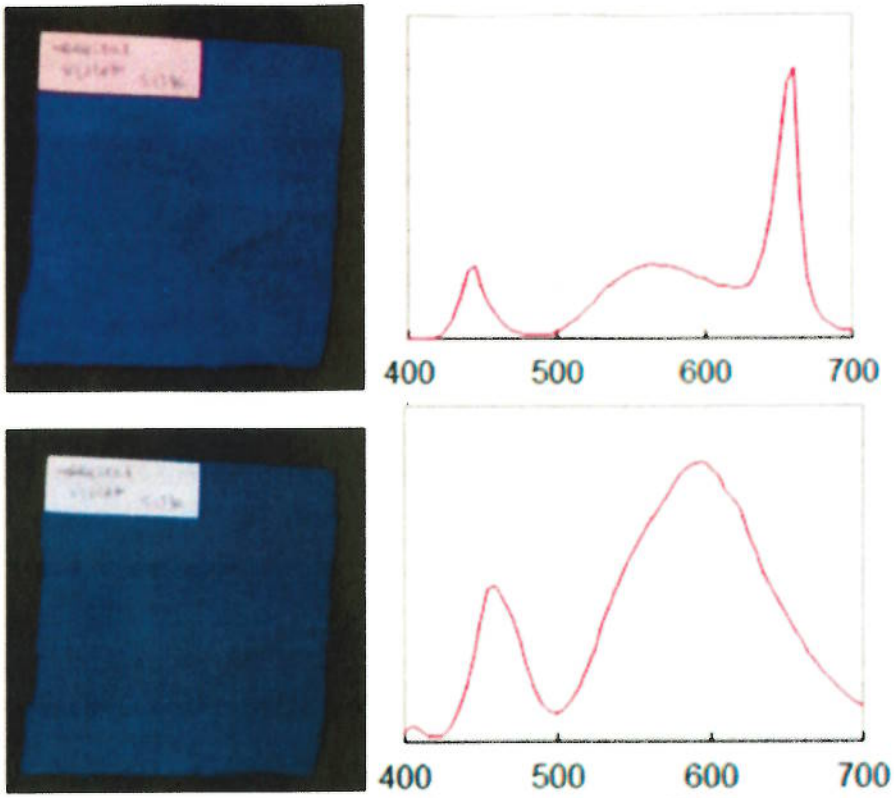


Figure 3: Crystal Violet on silk shown under two 3000-K LEDs

LEDs. Subsequent research has shown that multiple purple spectra including those of Tyrian (royal) purple (CI Natural Violet 1), Mauveine (Basic Dye, CI 50245) and Prussian blue (C.I. Pigment Blue 27), are all subject to color distortion (Bolin and Ballard 2014) under different light spectra.

During visual assessment, we also found that a lamp with a *low* CRI value, measuring the inability of its light source to illuminate objects faithfully in comparison to an ideal or natural light source (usually incandescent), did not always prove to be a poor choice. Deviation from incandescent properties could be beneficial to museums by increasing color saturation under low levels of light while still maintaining a neutral background. In Figure 4, a silk sample dyed with Congo Red is shown under two different LED spectra. Both spectra have same CCT and illuminance, but the SPD and CRI are different. The SPD of the low CRI LED (fig. 1, F) affects the range of the color gamut and creates a stronger red, a more saturated appearance of the Congo Red sample. Normally this would not be desirable—the color could become oversaturated. Yet, with faded objects the color would look more vibrant to viewers even at low illuminance levels (less than 50 lux). This could prove beneficial when it is desired to maximize the color seen with low levels of light.

After creating the spectra and exposing the dyed textiles, it was also determined that LEDs with specially formulated SPDs may offer many possibilities to museums. The lamps are very energy efficient and can be designed to offer options minimizing absorbed light and increasing the color saturation seen by observers. Because there are many available materials for LEDs, manufacturers can create unique spectra very unlike those of more traditional light sources; however, this will create issues in defining lamps and lighting. In the past, illuminance level (lux or foot-candles) and color temperature may have been used to communicate lighting with incandescent sources; other specifications will be necessary with LEDs.

Figure 4: Congo Red on silk sample shown under two LEDs with different CRI values, (left) low CRI; (right) high CRI

## 4. CONCLUSIONS

LED lighting can affect the color appearance of dyed historic textiles and the color distortion can be hue specific. Overall, the present study indicates that the SPD is required to communicate an LED's color rendering characteristics and to predict a lamp's suitability for use on a case-to-case basis. The SPD, often provided by LED manufacturers, may be useful in predicting color-distortion issues and specifying lights for exhibits. The study also confirms that current metrics used to communicate lamp specifications (e.g., CRI, CCT, illuminance) are neither adequate nor informative when communicating precise specifications for LEDs to be used in exhibits of dyed historic textiles, especially those with bright chroma, multiple color ways, or interplays of hue. The CRI and the CCT were not suitable criteria for predicting this distortion and should not be used to specify lighting for their exhibits; SPD information is required.

Purple hues seem particularly vulnerable to distortion by indiscriminant lighting with LEDs. Although we used known dyes for this study, textile conservators and conservation scientists might be able to use the NIST program to predict the effect of an LED with a known SPD on any dye where reflectance spectra are available. The reflectance curves of dominant colors—with known or unknown dyes—of textile objects can be inserted into the NIST program to predict the color distortion. By fine-tuning the interaction of the LED's particular SPD with the reflectance data of the dominant or more important colors or tones, conservators, lighting designers and conservation scientists eventually may be able to enhance the colors, even purples and reds, of a historic textile with lower overall illuminance values (lux or foot-candles).

## ACKNOWLEDGMENTS

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*Energy Independence and Security Act of 2007.* Public Law 110–140 110th Cong., 1st sess. (December 19, 2007). Accessed May 6, 2015. http://www.gpo.gov/fdsys/pkg/STATUTE-121/pdf/STATUTE-121-Pg1492.pdf

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## SOURCES OF MATERIALS

Dyes were obtained as commercial samples from a variety of companies in preparation for the Schweppe courses and kept sealed in dark storage (powders) or frozen bags (natural dyes). Dyes are often considered eye irritants and some early synthetic dyes are potential carcinogens. Please consult safety literature including data found on Important Early Synthetic Dyes on the MCI website.

Test Fabrics
415 Delaware Avenue
PO Box 26
West Pittston, PA 18643
Tel: 570-603-0432
Fax: 570-603-0433
www.testfabrics.com

Hunter Associates Laboratory, Inc.
11491 Sunset Hills Road
Reston, VA 20190
Tel: 703-471-6870
Fax: 703-471-4237
www.hunterlab.com

Sigma-Aldrich, Inc.
3050 Spruce Street
St. Louis, MO 63103
Tel: 1-800-521-8956
www.sigmaaldrich.com

Organic Dyestuffs Corporation ("Orco").
65 Valley Street
East Providence, RI 02914
Tel: 401-434-3300
Fax: 401-438-8136
http://organicdye-px.rtrk.com/

International Dyestuffs Corp.
PO Box 2169
Clifton, NJ 07015
Tel: 201-778-0122
(No longer in business)

Carolina Color and Chemical Corp.
PO Box 5642
Charlotte, NC 28225
Tel: 704-333-5101
(No longer in business)

Passaic Color and Chemical Co.
28-36 Paterson Street
Paterson, NJ 07501
Tel: 201-279-0400
(No longer in business)

Earth Guild
33 Haywood Street
Asheville, NC 28801
Tel: 828-255-7818
Fax: 828-255-8593
www.earthguild.com

Kremer Pigments
247 West 29th Street
New York, N.Y. 10001
212-219-2394
http://shop.kremerpigments.com/

| Dyestuff | C.I. Name | C.I. Number | Manufacturer/Supplier |
|---|---|---|---|
| Napthol Yellow | Acid Yellow 1 | 10316 | (past mfr: International Dyestuffs Corp.)<br>Sigma-Aldrich, Inc. |
| Uranine A | Acid Yellow 73 | 45350 | (past mfr: Carolina Color and Chemical Corp.) Kremer Pigments |
| Auramine | Basic Yellow 2 | 41000 | Sigma-Aldrich, Inc.<br>(past mfr: International Dyestuffs Corp.) |
| Chrysoidine | Basic Orange 2 | 11270 | Sigma-Aldrich, Inc.<br>(past mfr: Passaic Color and Chemical Co.) |
| Crystal Violet | Basic Violet 3 | 42555 | Sigma-Aldrich, Inc. |
| Diamond Green B | Basic Green 4 | 42000 | Sigma-Aldrich, Inc. |
| Magenta | Basic Violet 14 | 42510 | Organic Dyestuffs Corporation and Sigma-Aldrich, Inc. |
| Rhodamine 6G | Basic Red 1 | 45160 | Sigma-Aldrich, Inc. |
| Vesuvin BA | Basic Brown 1 | 21000 | Sigma-Aldrich, Inc.<br>(past mfr: Passaic Color and Chemical Co.) |
| Victoria Blue B | Basic Blue 26 | 44045 | Sigma-Aldrich, Inc. |
| Congo Red | Direct Red 28 | 22100 | Sigma-Aldrich, Inc. |
| Safflower | Natural Red 26 | 75140 | Earth Guild |
| Turmeric | Natural Yellow 3 | 75300 | Earth Guild, Kremer Pigments |

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