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# Testing and Evaluating Dye Color: A Study Using Spectrophotometry on Technicolor and Eastman Color Motion Picture Film

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# Testing and Evaluating Dye Color: A Study Using Spectrophotometry on Technicolor and Eastman Color Motion Picture Film

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# Contents

**Abstract**

The history of color motion picture film is linked to two companies: Technicolor and Eastman Kodak. Technicolor was formed in 1915 by Herbert Kalmus, Daniel Comstock, and W. Burton Wescott, who realized that color film could enhance motion picture entertainment. Introduced in 1932, it was a three-color process that was widely used into the late 1950s. The three-color process utilized a camera with one lens that exposed three black and white negatives simultaneously by splitting the incoming visible light through a prism. The prism would create two beams of light which would then expose one film negative to green light and the rest of the split light exposed a red and blue bi-pack comprised of two film negatives placed emulsion to emulsion.[1] One film negative would be sensitized to blue light while the other to red light, once exposed, the two negatives would be separated to be processed. The Eastman Color process, developed by Eastman Kodak Company in 1950, was similar to Technicolor. Eastman Color used three light-sensitive emulsions that were sensitized to red, green, and blue light which were then coated onto a single film base.[2] Having all three emulsion layers on one film support does away with the bulky three-color process camera used in the Technicolor process.

Eastman Color prints were less costly to produce than Technicolor prints. This was because Eastman Color only used one film negative versus Technicolor's three. Within a decade, Eastman Color films began to show evidence of fading in the negatives and prints. The film industry's shift from Technicolor to Eastman Color film resulted in a shift in the color, tone, and color balance of the film prints. Technicolor three-color dye process produces a very stable color

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[1] Scott Higgins, "Demonstrating Three-Colour Technicolor: "Early Three-Colour Aesthetics and Design," *Film History* 12, 4 (2000): 358-383.
[2] Doug Nishimura, Email correspondence with author, June 3, 2015.

that doesn't easily degrade with hues that were "warm," whereas Eastman Color tended to be "cooler" and almost neon-like.

In this thesis, I will discuss the differences in dyes used by Technicolor and Kodak and illustrate how the dyes have altered over time. To do so, I have made measurements on dyed film test strips by using a spectrophotometer that was created specifically for this testing. I sampled twenty-five test dyed film strips and twenty-five Technicolor film reels. In addition, a single Eastman Color film reel was tested. This sample size of fifty-one items yielded raw data that was calculated into absorbance and transmittance wavelengths. These spectral curves allow for comparison between the dyes used and for an evaluation of the colors. In the discussion, I describe why knowledge of dye fading is important to museums and how spectral information on dyes could improve film preservation efforts. This data is analyzed by reviewing scholarly journals, case studies, and first-hand accounts of dye tests in an effort to further the knowledge for museums and professionals with a focus on information on motion picture film, preservation, and spectrophotometry.

**Introduction**

The film industry was transformed by the introduction of color into motion pictures. Since the introduction of color, there have been a number of companies competing to produce a superior product, the two most prominent being Technicolor and Eastman Kodak Company. Technicolor made a name for itself based on its color and stability. This reputation was the result of the immense amount of research they conducted. The research department could make changes on a whim based on test prints. Production changes and notes would have not been kept due to their relative unimportance at the time. Patent information is also unreliable, just because they had a patent, it doesn't mean they used that product more than once. As a result, there has been no definitive way to identify dyes used in the production of Technicolor films.

This thesis will strive to illustrate the benefits that spectrophotometry can provide to the motion picture preservation field. By using a non-destructive test like spectrophotometry, a film archive could gather useful data about the materials in their collection that could be beneficial as a tool to monitor preservation.

**The Technicolor Corporation**

Incorporation papers were submitted in November of 1915 under the name of Technicolor. Herbert Kalmus created the name for the company by using the yearbook title from his alma mater, the Massachusetts Institute of Technology (MIT). The title of the yearbook was *Technique* and Kalmus added the word color at the end. Research was not funded by motion picture companies, but was privately funded, then licensed to outside organizations. The introduction of color film also created changes in how motion pictures were filmed.

Professionals were inexperienced in choosing colors for makeup, sets, and costumes. Until Technicolor created their color consultancy division, the Technicolor cameramen were charged with the responsibility of making sure the right colors were chosen in order for them to look correct once filmed. By 1931, the Technicolor research department was working towards "good color" and began testing dyes from a variety of manufacturers. As the testing proceeded, different concentrations and proportions were attempted until they achieved best results.[3]

**The Technicolor Three-Color Process**

After an earlier failed effort, Herbert Kalmus, Daniel Comstock and W. Burton Westcott developed the three-color camera and process in 1932. The three-color camera was large and cumbersome because it exposed three film negatives to light simultaneously. By using a prism and mirror, the beam of light entering the camera was divided into two separate beams of light. One beam of light was projected through a green filter onto the film stock. The green filter was exposed directly onto a black and white film stock. This made the green, black, and white colors the sharpest in the images.[4] The rest of the split light exposed a red and blue bi-pack comprised of two film negatives placed emulsion to emulsion. For this film to receive accurate color information before reaching the bi-pack, the light had to pass through a magenta filter which absorbed green light. With the green spectrum absorbed, the light would first expose the blue

[3] James Layton and David Pierce, *The Dawn of Technicolor, 1915-1935*, Rochester, New York: George Eastman House, 2015.
[4] Richard W. Haines, *Technicolor Movies: The History of Dye Transfer Printing*, Jefferson: McFarland & Company, Inc., Publishers, 1993.

sensitive film stock. Finally, the light passed through a red-orange filter which absorbed the remaining blue light to expose the red sensitive stock to red light.[5]

**Developing Technicolor Film**

After the negatives were exposed to light, they were then projection printed, meaning an image was projected onto a printing medium using a lens system. The images were projected onto stock (which is simply blank film) carrying a thick layer of gelatin that would harden where it was exposed. Where the gelatin was not exposed, it would wash away, leaving a relief image of a particular record of color. This relief image was referred to as matrix stock, which functioned like a rubber stamp that transferred the color image to a release stock known as the blank. The matrix positive was coated in a subtractive primary dye which was the complementary color of those registered on the film negatives. For example, the film negative which was exposed to blue light would then be coated in yellow to be printed. The additive colors used in the camera, red, green, and blue would be replaced by subtractive colors cyan, magenta, and yellow.[6] Additive color mixing is most commonly recognized as the mixing of light. Color filters of red, green, and blue when mixed together equally create black. Common examples of additive color mixing are television and computer screens. Subtractive color mixing deals with how we view colors that are printed. When magenta, yellow, and cyan are mixed, they create the colors used in subtractive mixing.

The motion picture prints were made by a dye transfer process which was also known as the imbibition printing process. Through this process, a matrix passed through a dye tank where

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[5] Scott Higgins, "Demonstrating Three-Colour Technicolor: "Early Three-Colour Aesthetics and Design," *Film History* 12, 4 (2000): 358-383.
[6] Scott Higgins, "Demonstrating Three-Colour Technicolor: "Early Three-Colour Aesthetics and Design," *Film History* 12, 4 (2000): 358-383.

it came into contact with a blank roll of film. Pressure was placed onto them in a heated path for roughly a minute then the blank and the matrix separated. Once the blank cooled, it was subjected to water jets that washed the excess dye away to a specified density. This process, known as the wash-back mechanism, made it possible to precisely and independently manipulate each of the colors' density and contrast. The control gained by the wash-back system was something that was lost when using a photo-chemical process, which is when an impression is recorded by light being exposed to surface coated with silver atoms. Before the color could be applied, the blank was treated with a gray half-tone exposure generated from the green record. This image served to enhance shadow detail and contrast. When color is applied to the blank, the order of the color transfer process begins with yellow, cyan, and then magenta.[7]

**The Eastman Kodak Company**

As a young man in his 20s, George Eastman invented his own photographic emulsion and a machine that could quickly prepare dry plates for photography. Once he received a patent for his coat plating machine in London and the United States, his new business was underway. Eastman experienced continued success by focusing on the customer and providing a quality service at a reasonable cost.[8] Eastman established a reputation for manufacturing high quality film in great quantities. All Eastman required to produce such film was clean air and water, organic materials, tanks of dye, and tons of pure silver. There was also a strong commitment to research and development.[9]

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[7] Scott Higgins, "Demonstrating Three-Colour Technicolor: "Early Three- Colour Aesthetics and Design," *Film History* 12, 4 (2000): 358-383.
[8] "George Eastman," George Eastman, Accessed April 21, 2015, http://www.kodak.com/ek/US/en/George_Eastman.htm.
[9] Craig Jones, *The Book of Film Care*, Rochester, New York: Eastman Kodak Company, 1983.

**Eastman Color**

Eastman Kodak introduced Eastman Color in the 1950s; it was a simpler and less expensive process than Technicolor. The savings for the motion picture companies were immediate. This led Kodak to franchise the process to a variety of laboratories, resulting in various trade names, like Color by Deluxe and Warnercolor. Dye-coupler color printing became so broadly accepted in the nineteen seventies that Technicolor changed to the dye coupler process. Dye-couplers are partial dyes that form dyes by reacting with an oxidized developing agent, which is created by the developing agent acting on exposed silver halide crystals. This new process eventually led to the closure of Technicolor imbibition printing plants.[10] Eastman Kodak's color film consisted of three layers of dye-couplers which create a single color sensitive film which produced a color image. The three strips were bonded together in a single, tri-pack roll which would simultaneously react to develop a separate dye image in each layer. The dye image would create the complementary to each layer, which corresponds to the original scene.[11] "Kodak's color process allowed the film to pass through a camera once. All colors were exposed and subsequently developed in the lab at the same time."[12] Eastman Color could be shot with a one lens camera. Within two or three years of the introduction of Eastman Color, nearly every major studio adopted it.[13] Kodak's new process permitted shooting in environments that weren't previously accessible by Technicolor, which allowed shooting to occur in any weather and any

[10] Paul C. Spehr, "Fading, Fading, Faded-The Color Film Crisis," *American Film* 5, 2 (1979): 56-61.
[11] Roderick T. Ryan, *A History of Motion Picture Color Technology*, New York, New York: Focal Press, 1977, 77, 148.
[12] Michael Bliss, "Technical Tips," *Classic Images* 73:58-59.
[13] Steve Neale, "Technicolor," *Cinema and Technology: Image, Sound, Colour*, Bloomington: Indiana University Press, 1985, 129-144.

lighting condition.[14] The film also allowed for shooting up to two hours longer than previously possible. Despite these benefits, new technical problems were discovered, such as the film needed to be kept at fifty degrees Fahrenheit and a maintained humidity of fifty-five percent.[15]

**George Eastman House Film Collection**

As a proud Rochesterian, I have always been quick to share the accomplishments of my hometown. Being the daughter of a former Kodak employee and being exposed to Kodak products my entire life has inspired my interest in what George Eastman has done for film and photography. I have always felt that the George Eastman House was a fantastic resource and contribution to our city. I knew that the house and museum were known internationally, but after beginning this research, I learned how extensive their reach and collections really are. The George Eastman House: International Museum of Photography and Film (GEH) was established in 1947 and is the third largest film archive in the United States. It houses approximately thirty thousand motion picture titles and over four million objects, which include photographs, posters, papers, books, motion pictures, cameras, and technology.[16]

In 1981 the George Eastman House acquired collections from Technicolor, including notebooks, cameras, papers, and dye bottles. In 2009, Technicolor gifted their corporate archives. In addition, the George Eastman House stores the largest collection of Technicolor yellow, cyan,

[14] Cave, "Eastman All-Weather Tint Highlights 'Royal Journey'—The Hollywood Reporter, 1/17/52," January 17, 1952, Andreas Collection, Andreas Box 4. Color Processes- Others (folder, 1952, George Eastman House: International Museum of Photography and Film, Rochester, NY.
[15] Carpenter to Clark, Cave, Harrison, January 2, 1952, Andreas Collection, Andreas Box 4, Color Processes- Others (folder, 1952), George Eastman House: International Museum of Photography and Film, Rochester, NY.
[16] "About," About, January 1, 2015, Accessed April 15, 2015, http://eastman.org/technicolor/about.

and magenta negatives in the United States.[17] The collection also contains photographs, documents, and equipment that amount to approximately sixty thousand artifacts.[18]

**Color Fading Concern**

Color motion picture film was never meant to be permanent; the color dyes are basically unstable and are subject to fading. Hollywood was never concerned about preserving motion picture film. There was a short life expectancy of one to two years placed on prints for theatrical release; a very popular film could wear out in a matter of months.[19] The public and Hollywood never seemed interested or invested in the archival qualities of their film choice.

Due to the competition between Eastman Color and Technicolor, Technicolor considered advertising their imbibition process by highlighting its excellent stability. One of the reasons that color problems existed, was in part due to processing the film too quickly. The color fading issue was made worse by movie studios and film archivists' lack of knowledge about how film should be stored. Eastman Color prints and negatives stored at normal conditions suffered a shorter life in comparison to Technicolor films.[20] An additional cause of fading dye is dark storage; the fading of dyes in the dark is a result of the lack of stability of the organic dyes used in a particular film. Unlike magenta and yellow dyes, cyan dye is more stable in light with the trade-off being that it's unstable in the dark. This instability causes the visible cyan dye to reduce to a

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[17] "The Motion Picture Collection," George Eastman House Rochester, Accessed April 15, 2015, https://www.eastmanhouse.org/collections/motion-picture.php.
[18] Gary Price, "Film History: Eastman House Gets $100k NEH Grant To Help With Online Archive," LJ INFOdocket, March 23, 2015. Accessed April 16, 2015, http://www.infodocket.com/2015/03/23/film-history-eastman-house-gets-100k-neh-grant-to-help-with-online-archive/.
[19] Paul C. Spehr, "Fading, Fading, Faded-The Color Film Crisis," *American Film* 5, 2 (1979): 56-61.
[20] Henry Wilhelm and Carol Brower, "The Permanent Preservation of Color Motion Pictures," *The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures*, 1993, Reprint, Grinnell: Preservation Publishing Company, 2013, 299-344.

colorless state .[21] Other factors reducing the stability of the negative or print film are the temperature and relative humidity of the storage area, and improper processing.

The dye stability issue with Eastman Color became a growing concern for filmmakers who witnessed the colors of their films suffering. Martin Scorsese was affected by the dye fading; his films, such as *New York, New York* (1977) were in jeopardy of fading beyond recognition.[22] Scorsese made the decision to film *Raging Bull* (1980) in black and white to prevent witnessing another film succumb to unstable dyes. Scorsese's passion about preservation caused him to start a petition asking Kodak to create a permanent color motion picture film. When color fades, it is proportional within a single density of color, which results in a loss of image contrast. It is possible to correct the change in density, but once contrast is lost, there is no way to restore it.[23] When an image is lost due to the fading of dye, there is no way to fix it. Once the dye has faded from an image, no amount of rebalancing color would provide hints to what the image once was.

**Industry Standards for Storage**

Motion picture film is finicky to store and environmental factors play a large role in how well it will survive. The main culprits of film degradation are temperature, relative humidity, time, and light. It has been found that the best way to preserve motion picture film is in a temperature and humidity controlled facility. The preferable storage temperature is between thirty-two and forty-five degrees Fahrenheit, with colder temperatures being more desirable,

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[21] R.J. Tuite, "Image Stability in Color Photography," *Journal of Applied Photographic Engineering* 5, no. 4 (1979): 200-07.

[22] Martin Scorsese, "Martin Scorsese on the Color Crisis," *Film Comment* 16, no. 1 (1980): 79.

[23] Henry Wilhelm and Carol Brower, "The Permanent Preservation of Color Motion Pictures," *The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures*, 1993, Reprint, Grinnell: Preservation Publishing Company, 2013, 299-344.

especially for film that has already shown evidence of color fading and/or those known to have poor color stability. The relative humidity of the storage facility is as important as the low temperature. The ideal range for relative humidity is between twenty-five and forty percent, with twenty-five percent being the ideal number.[24] The cold storage room should be kept dark; while this is an issue for the stability of the cyan dye, it is primarily beneficial for magenta dyes as that is the one most vulnerable to fading in light. Motion picture film is fragile; once it starts to degrade, there is very little that can be done to return the medium to its original condition. Placing film in cold storage as soon as possible slows the degradation process. Storing film reels in vapor permeable containers is another prevention tool, though it has been proven that the type of film enclosure plays no significant role in preventing off-gassing of acetate based films.[25] Preventing film base deterioration is important, especially with the off-gassing of acetate-based films. Film base deterioration can affect playability by causing the film to shrink. Motion picture film is a composite of a variety chemicals, from the film base to the dyes that constructs the image, and the degrading of one can negatively interact with others, potentially hastening the fading of the dye. An example of such dye fading is yellow dye, the acid from the deteriorating film base makes the bonding of water molecules easier to attach to the dye molecule, which accelerates the fading.

When physically storing film containers on shelves within a storage facility, the containers should be stored horizontally with no more than eight cans stacked on top of each

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[24] Henry Wilhelm and Carol Brower, "The Permanent Preservation of Color Motion Pictures," *The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures*, 1993, Reprint, Grinnell: Preservation Publishing Company, 2013, 299-344.

[25] Jean-Louis Bigourdan, "Stability of Acetate Film Base: Accelerated-Aging Data Revisited," *Journal of Imaging Science and Technology* 50.5 (2006): 494-501.

other.[26] This prevents too much weight from accumulating, which can endanger the safety of the archivist and crush the film reels.

The George Eastman House has three storage facilities to house their motion picture collection. The storage on-site is kept at the temperature and relative humidity range described in the previous paragraph. The Eastman House tries to sustain a temperature of forty degrees Fahrenheit and a relative humidity of thirty percent. The acclimation room is kept around fifty-five degrees Fahrenheit with a relative humidity of forty percent. Like at any location, it is difficult to maintain these levels as there is usually some fluctuation depending on the outside conditions. Before viewing any films in cold storage, the film must acclimate in temporary storage as the temperature is slowly increased to normal for a day or two.

**Spectrophotometry**

Spectrophotometry could be a useful tool for museums; conservators could use spectral imaging on photos, posters, and other objects within the scope of their collections. This equipment is expensive and requires a professional to interpret and efficiently utilize information obtained. Spectral curves create a scientific description of color using a unit of measure in nanometers (nm). A spectral curve acts like a finger print of a color, each color is uniquely different and the spectral information would reflect that. Even if the wavelength values register a zero percent, it still helps characterize the dye. Having access to this equipment and information could help a museum or collection produce more accurate reproductions of an object's color for print publications or for a website. When imaging objects and works of art, we view the image

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[26] Henry Wilhelm and Carol Brower, "The Permanent Preservation of Color Motion Pictures," *The Permanence and Care of Color Photographs: Traditional and Digital Color Prints, Color Negatives, Slides, and Motion Pictures*, 1993, Reprint, Grinnell: Preservation Publishing Company, 2013, 299-344.

through multiple digital formats. Each time the image is viewed on different screens and in different formats, the color changes. Being able to apply a number to a color makes it possible to consistently and accurately repeat the color, which assures that the color is accurate. Spectral imaging can also aid conservators in determining if an object has experienced color shifts over a period of time. Paintings, inks, paper, and photographs are just a few examples of items that have sensitivity to light. Displaying objects for a long period of time could potentially cause damage; the curves could provide definitive proof of the change.

Research departments at Technicolor and Eastman Kodak would perform similar tests to spectrophotometry. Densitometry is the measurement the optical density in light sensitive materials, such as motion picture film. Densitometers have standard filters that have light projected through them, with the filter being the opposite of the sample you are testing. For instance, if you wanted to test how much light you receive through a yellow sample, a blue filter would be placed in front of the light source. This type of testing was and is common when deciding viability of dye.

Spectrophotometry has been used in an experiment previously, to investigate a mathematical bleaching of motion picture dyes. In this instance, the dye was applied to a paper substrate and used a reflective spectrophotometry since the base is opaque. The spectral information is gained from the visible light that reflects back to the sensor in the spectrophotometer. The data was recorded at different increments and like the testing I completed, they represent a specific moment in time.[27] The data obtained over time can then be compared in a line graph that illustrates measurable changes to the dye.

[27] Franziska Frey and Rudolf Gschwind, "Mathematical Bleaching Models for Photographic Three-Color Materials," *Journal of Imaging Science and Technology* 38, no. 6 (1994): 513-19.

Previous scholars would not have access to any research materials regarding what dyes were used, since it wasn't considered important enough to save.[28] There has only recently been interest in, and education on, proper storage and preservation of motion picture films. The Technicolor collection at the George Eastman House is unique because of its film strips to test dye colors and bottles of the original dye bottles with powder remaining inside. These provide insight and understanding into dyes used.  Recording spectral information about motion picture film as soon as possible, could provide a baseline from which to measure future deterioration.

**Description of Tools and Techniques**

I designed a platform for testing three selections from the Eastman House collections: Technicolor imbibition prints, Technicolor dye test strips, and Eastman Color positive prints. Each of these films were imaged using a spectrophotomer to reveal both transmittance and absorption of the dyes that were used. From my research, I have not found any spectral studies performed on motion picture film. Traditionally, spectrophotomers are used in the sciences to analyze biological solutions or to identify gemstones by their reflectance.

A spectrophotometer measures the amount of light that transmits or reflects through a sample at each wavelength in the range of the human visual system. A Spectrophotometer can also be used to measure ultra violet (UV) and infrared (IR) light which is invisible to the human visual system. For my testing, I only focused on visible spectroscopy but future testing would benefit from testing the IR and UV range. UV and IR can possibly reveal new hidden information that can be valuable to understanding dye fading. The spectrometer is necessary to differentiate various dye colors on a blank film strip. The GEH dye test film strips, created by

[28] Ronald Sagen, Discussion, August 15, 2014.

John Andreas, were made available to me. John Andreas was the head of research at Technicolor beginning in the 1930s; he tested and analyzed hundreds of dyes for possible use in motion picture film production. With the assistance of William Ryan, a professor in the Chemistry Department at Rochester Institute of Technology, I created my own spectrophotometer. A light box was created by using an empty Staples copy paper case measuring 18"L x 10"W x 15"H and a portable spectrophotometer from Ocean Optics, a Red Tide USB 650. Within the box, we placed a single light socket with a clear tungsten twenty-five watt bulb (the coated bulbs are band filters which alters the amount and type of light). The lid had an approximately one inch square cut out of it, into which a piece of clear Lexan (polycarbonate) was taped. Lexan is a polycarbonate resin which is impact resistant, permits light transmission, and maintains glass-like clarity.

The Ocean Optics spectrophotometer was attached with double stick tape to another piece of clear Lexan, allowing us to sandwich the film strip between the two and keep it in place without causing damage. With our spectrometer set up, we connected a USB cable to the Red Tide spectrometer and an RIT property laptop that had Ocean Optics software downloaded. The software allows the user to view live spectral curve data from the light box. We attached double stick tape to the sheet of Lexan that was attached to the box; the double stick tape was placed in three positions so that we could consistently repeat the placement of the spectrometer.[29] This is important because the light source needs to remain in one position as changes could cause the sensor to be exposed to more light, altering the spectral curve.

[29] See Appendix 1.

**Selection of Materials and Process**

For testing, I selected twenty-five dye test strips from three of twelve banker boxes in the George Eastman House collections. The banker boxes measured 10"L x 12" W x 15"H, and each contained four smaller boxes. Each of the smaller boxes contained hundreds of 5"Wx7H" or 4"Wx6"H notecards that had one to two dye test strips stapled to them.[30] The notecards represented a specific dye with its unique chemical equation and structure annotated. Andreas occasionally added a date, or notes about how the color appeared or its stability, along with spectral density curves of the color drawn to provide more information. Andreas occasionally wrote an alpha-numeric title on the notecard to identify the dye; I believe this number corresponded to the number written on the glass bottles that contain powdered dye owned and saved by Andreas.

While conducting this work, I wore white cloth gloves to protect the film from the oils on my skin. I then thumbed through the notecards and picked samples of cyan, magenta, and yellow. Occasionally, I found samples that fell into a dark blue, green, or purple and would record the spectral curves. Sandwiching the samples between the two pieces of Lexan provided consistency in placement, it also created ease of use in testing alternating samples. Slight adjustments were made to accommodate the variation of the test dye strip's length, since we were not permitted to remove the staple to separate the test strip from the notecard. By changing the placement of the Ocean Optics device closer to the long edge of the Lexan made the testing process more efficient because we could then accommodate a variety of dye test strip lengths. Once the changes were made, the testing was a breeze. A measurement was recorded only of the tungsten light source passing between the two pieces of Lexan. While viewing the

[30] See Appendix 2.

curve live through the Ocean Optics software, slight adjustments were made to create less noise in the curve. Similar to setting a shutter speed on a camera, the integration time takes a signal and averages the information that is hitting the sensor. We set our integration time to a seven and the scans to average to sixteen. The scans are across a wavelength, six hundred and fifty data points, to assemble and average. By setting a number within the scans to average field, creates consistency in the data, instead of it automatically changing.

After making adjustments to our empty data points, we tested strip that was previously dyed red and had completely faded over time, providing us with a blank piece of film stock to use as our reference test. The reference measures the intensity of the light emission source, and taking multiple reference measurements throughout the process allowed us to note if the emission source increased or decreased in intensity. Once the reference data was recorded, we pasted the results into a column in Microsoft Excel. We began to use twenty-five color dye test samples, choosing primarily cyan, magenta, and yellow. Other colors would be chosen such as purple and greens to explore the potential variety in results. Each dye test strip created its own basic raw data curve within the software, which was fascinating to see. The curve could change drastically from a yellow to a dark blue or magenta. We continued like this for a few samples, using the given number written on the card as our sample name whenever possible and inputting the data into its corresponding column. After four or five tests were complete, another reference test was done to make sure the light was remaining consistent. If the light source's intensity had changed, that would affect our data results of the test dye strips. When the reference test data was recorded, we selected our empty and reference columns and plotted them in a line graph with Microsoft Excel to see how closely the data plotted and if there were any significant differences. We continued with our test dye strips with periodic reference tests. From our reference tests, we were able to determine that our tungsten light source was releasing more intense light than in previous tests. Those little changes make a difference when calculating the results and are important to note.

Our twenty-five tests were completed within four to five hours after which we calculated our raw data into absorbance and transmittance using Excel software. Absorbance is calculated by the logarithm of the raw reference data divided by the raw data from a dye test strip. For instance, to calculate absorbance for a single data point the equation would look like this: A= log (10.03/6.61)= 0.181099.[31] That equation represents a single data point at wavelength four hundred and thirteen nanometers (nm), a data point is a measurement at a certain instance that can be represented numerically and/or graphically. The entirety of these calculations for a single dye sample can be viewed in graph form in figure seven, where the x-axis is wavelength and y-axis is calculated absorbance.[32] The absorbance calculation had to be performed for each of the six hundred and fifty data points recorded, representing a single measurement in a moment of time.

The process was repeated to calculate transmittance for the twenty-five samples of the dye test strips out of a total of fifty-one. Transmittance is a measurement of the ratio of light being transmitted through a material, and is calculated by dividing the raw data from a dye test strip by the raw reference data. This is then multiplied by one hundred to get the percentage of transmitted light through the dyed film. For instance, to calculate transmittance for a single data point the equation would look like, T= (6.61/10.03)= 0.659023 or 65.9%.[33] That equation represents the a single data point at wavelength 413 nm, the entirety of these calculations for a

[31] See Appendix 3, for raw data for absorbance calculation.
[32] See Appendix 3.
[33] See Appendix 3, for raw data for transmittance calculation.

single dye sample can be viewed in graph form in figure seven, where the x-axis is wavelength and y-axis is calculated transmittance.[34]

The second component of my testing included twenty-five Technicolor imbibition prints that were sixteen millimeters (mm) in width. Our set-up was a little different this time. In order to look at reels of film a hand-cranked film winder was needed. The height of the film winder was advantageous because our light box was able to fit underneath the film being stretched between the two reels. The set up was different than what we used with the test strips. We used double stick tape to change our previous alignment on the box and Lexan. A path was created to allow the sixteen mm film to consistently be placed in the same position. Double stick tape was placed on the Lexan to be able to consistently and repeatedly place the Ocean Optics spectrometer that was attached to another piece of Lexan. The twenty-five Technicolor films were a combination of twelve films that were rolled with only a core in the center. The most time-consuming part of the testing process was the George Eastman House employee needing to open the plastic can containing the film print on a plastic core, even then, he moved fairly quickly. Then the film was placed between two metal reels which sandwiched the film to keep its shape and on a spool so the reel could be cranked. The film leader (a plastic that matches the film's gauge and is attached to the end of film to assist with threading it in a projector) was then brought across an approximate two-foot span to be threaded into another core and began to be wound onto the empty core. The film was then advanced to the point where there was enough of a solid color present in a single frame to garner data from. In this application, it was difficult to determine if the sensor was located over the specific color. We recorded the data for these samples because it was an amalgam of colors and interesting to record as there were a number of

[34] See Appendix 3.

mixed colors included in the dye test strips. One of the limitations of our equipment was that the fiber optic sensor could not narrow the field of testing on single frames of film. The fiber optic sensor had a twenty-five micrometer entrance aperture for light to pass through.

**Evaluation**

From both of these testing sessions, we were able to gather a substantial amount of data. The experiment on the single frames of film provided interesting information. The spectral curves were not of a single color, but represented a mixture of colors that the sensor received. When reviewing the results, we came across similarities in curves that illustrated potential for direct comparisons. The evidence of these similarities can be seen between figures eight and thirteen.[35] Viewing the graphs, you can see that where each curve is located on their respective graphs is in similar positions. The two graphs from figures eight and thirteen illustrate the absorbance measurement of a blue to green color, one from a dye test strip and the other from a film reel. The x-axis of the graphs is labeled in nanometers which is the measurement of the wavelength. The measurements of a blue color to green color fall between four hundred and thirty nanometers to about five hundred nanometers. When there is blue absorbance curve, the color that the viewer is seeing is yellow, which is what would be transmitted to our visual system. These two graphs are in no way a match, similarities and conclusions can be formed about pairing two dye samples. Additional tests may uncover an exact match but at this time, I can only illustrate the possibilities of this type of testing.

[35] Appendix 3 and 4.

The problem that arose during testing of single frames is that there was simply too much information revealed, as seen in figure fourteen.[36] With so much spectral information, there is no way to match a single dye to another. Comparisons can be made when viewing a spectral graph by looking at wavelength five hundred and ninety and at six hundred and sixty-one, these peaks represent the strongest intensity of color represented in the film and depicts the combinations that create the color.[37]

**Conclusion**

The museum field is an interesting one for the reason that it can encompass a variety of specialties. This is where my interests lie, between history and science. My thesis shows that there is more to learn about different objects and that other ways of experimenting and analysis can be applied. The testing that I completed demonstrates that tools such as a spectrophotometer can be used within the humanities fields and produce viable results.

The results from my testing did not create the ideal conclusion of being able to identify dyes used in production. There are two reasons why: the number of samples I tested was too small to garner a match and there were few instances when I would have a single color to test in a frame of film. This research could be expanded to gain spectral information on all the dye test strips, while a lengthy process could create an extensive and informational database for future use. The dye test strips were labelled occasionally with a date, chemical equation, and/or chemical structure. Having this information located in one place could provide the motion picture preservation field with usable information on the chemical structure of these dyes which would help with preservation and understanding of dye fade. Using a spectrophotometer on film

[36] See Appendix 4.
[37] See Appendix 4.

reels is also beneficial: the spectral curves will aid the matching of the dyes and also provides a benchmark to which other testing can be done. The spectral curves are a scientific description of color and when subsequent tests are completed, the comparison to previous tests may illuminate changes in the intensity of the dye color. If a full database was created, a preservationist could use it to compare earlier experiments to determine whether the dye has changed or not, and if it has, by how much and in which dye.

Appendix 1 Testing Apparatus

Figure 1. Light box with Ocean Optics Spectrometer with a test dye strip in place.


Figure 2

Same set up as above with one of the smaller boxes of test dye strips shown

Appendix 2 Raw Data

Figure 3. Raw data of Technicolor test dye strip taken 4/1/2015. Film samples from the George Eastman House, Box 6, Andreas Collection. Data and chart created by Bill Ryan and Melissa Sagen.

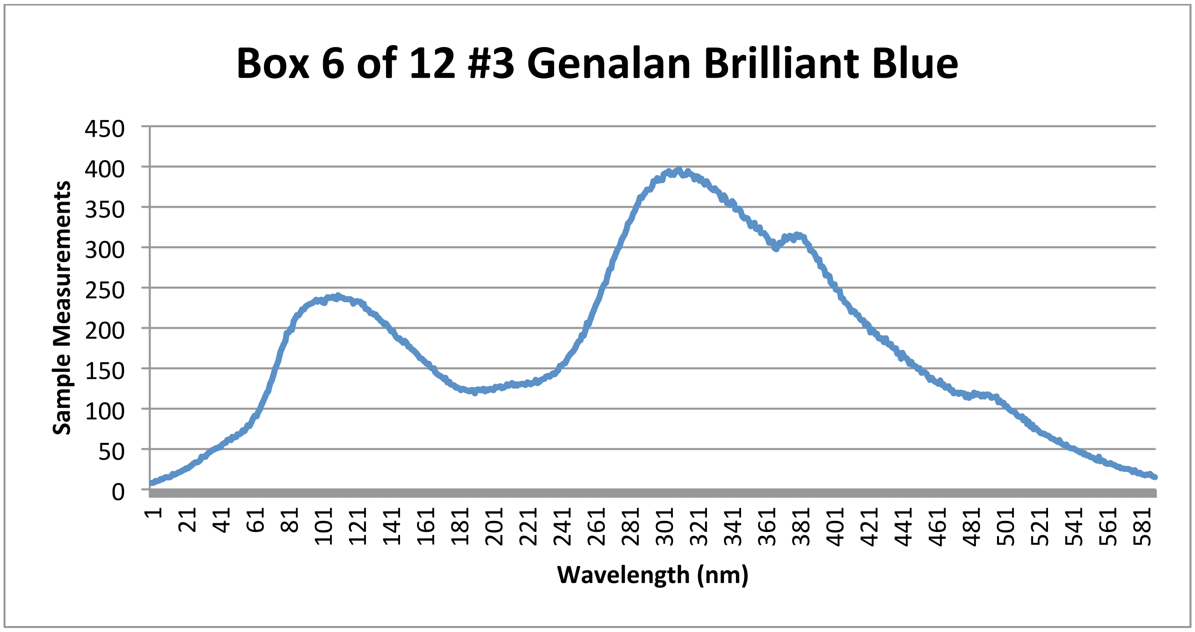



Figure 4. Raw data of Technicolor test dye strip taken 4/1/2015. Film samples from the George Eastman House, Box 12, Andreas Collection. Data and chart created by Bill Ryan and Melissa Sagen.

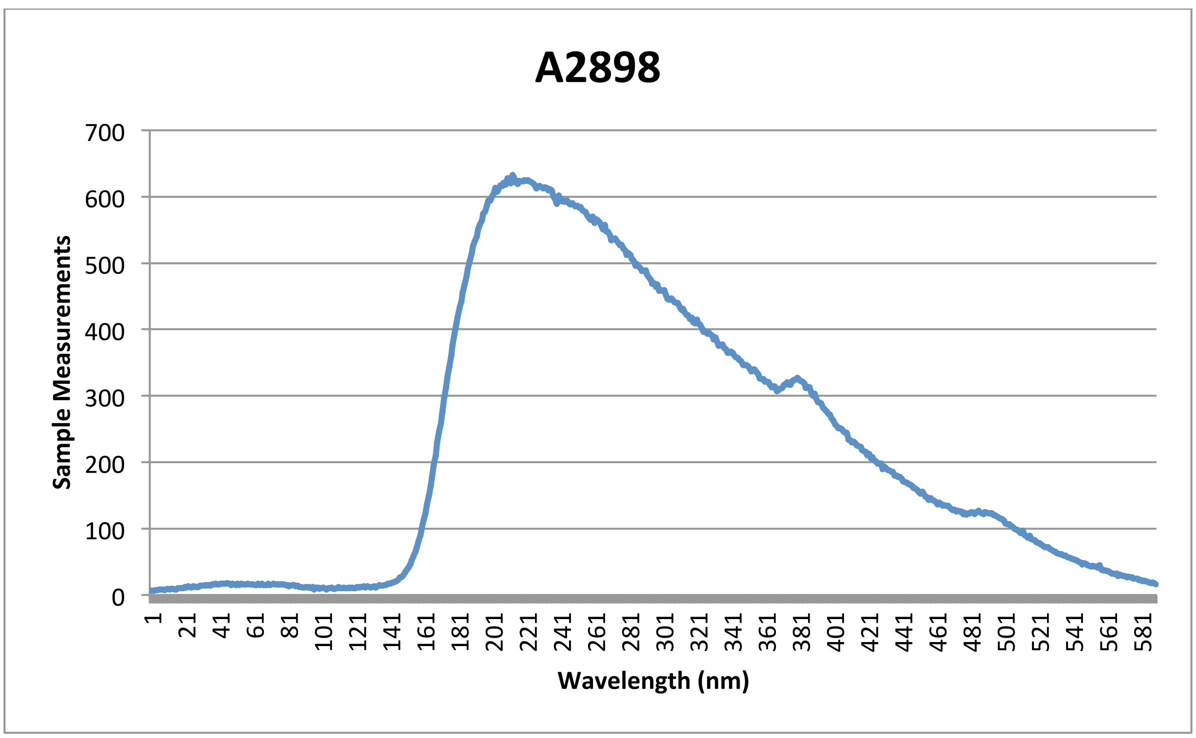
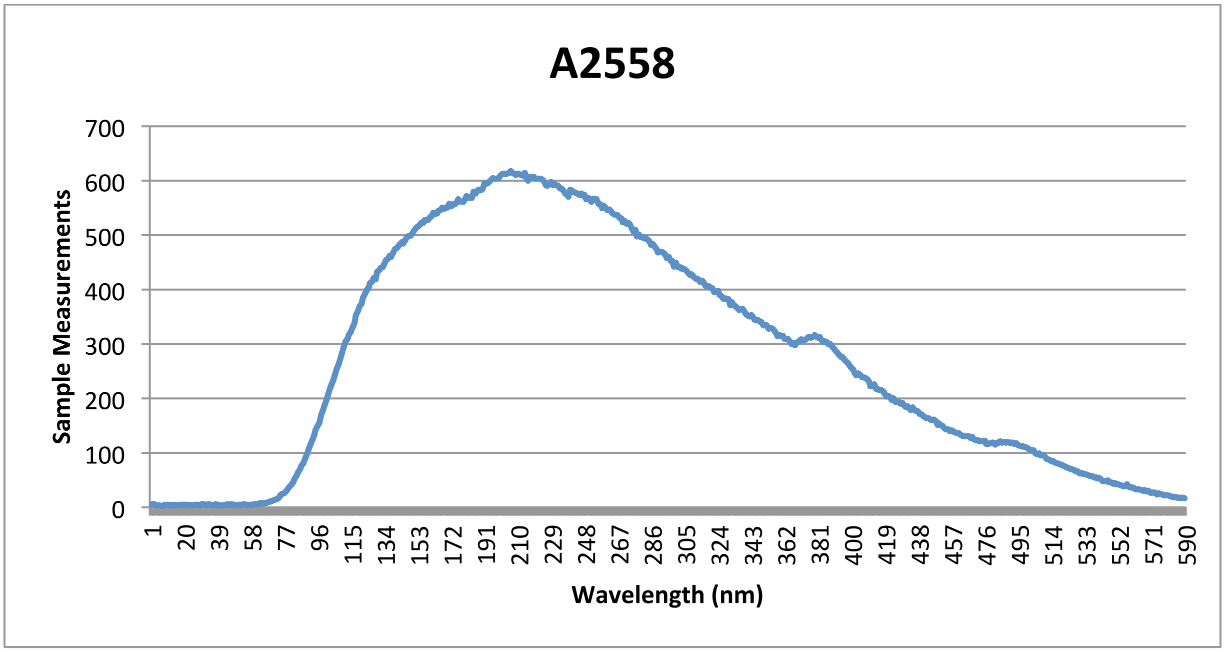


Figure 5. Raw data of Technicolor test dye strip taken 4/1/2015. Film samples from the George Eastman House, Box 12, Andreas Collection. Data and chart created by Bill Ryan and Melissa Sagen.




Appendix 3 Calculated Absorbance and Transmittance of Test Dye Strips

Figure 6. Absorbance data of Technicolor test dye strip taken 4/1/2015. Film samples from the George Eastman House, Box 6, Andreas Collection. Data and chart created by Bill Ryan and Melissa Sagen.

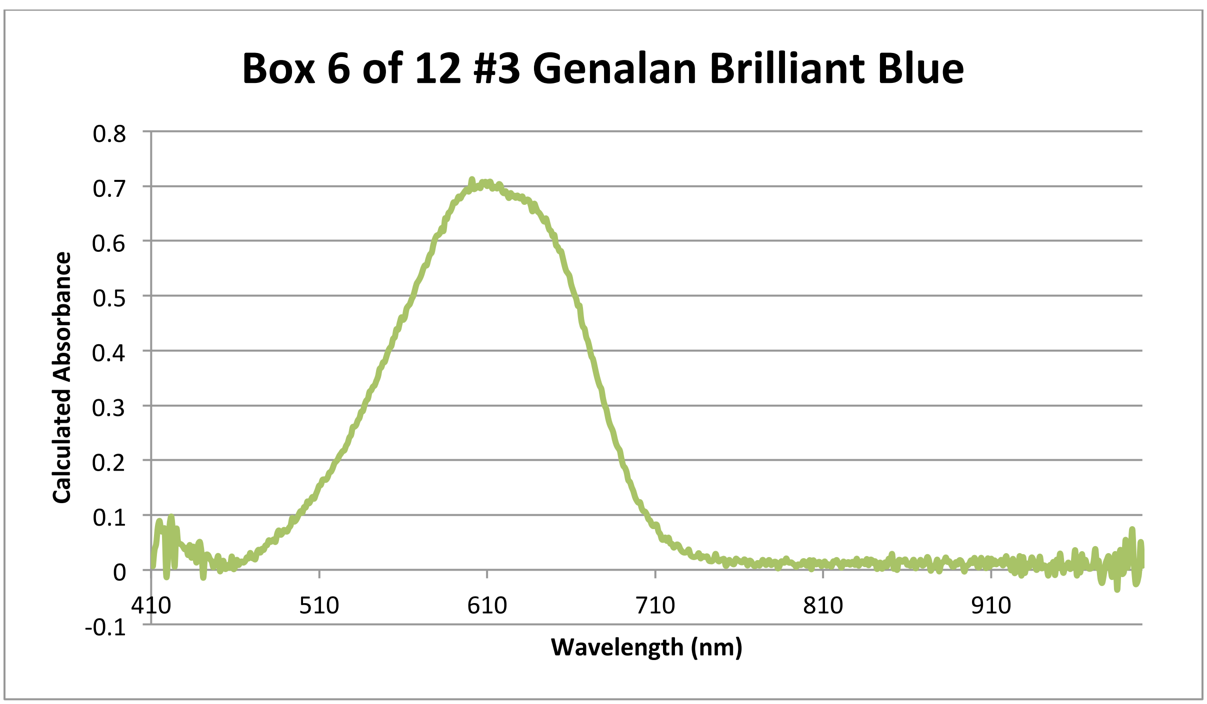


Figure 7. Absorbance data of Technicolor test dye strip taken 4/1/2015. Film samples from the George Eastman House, Box 12, Andreas Collection. Data and chart created by Bill Ryan and Melissa Sagen.

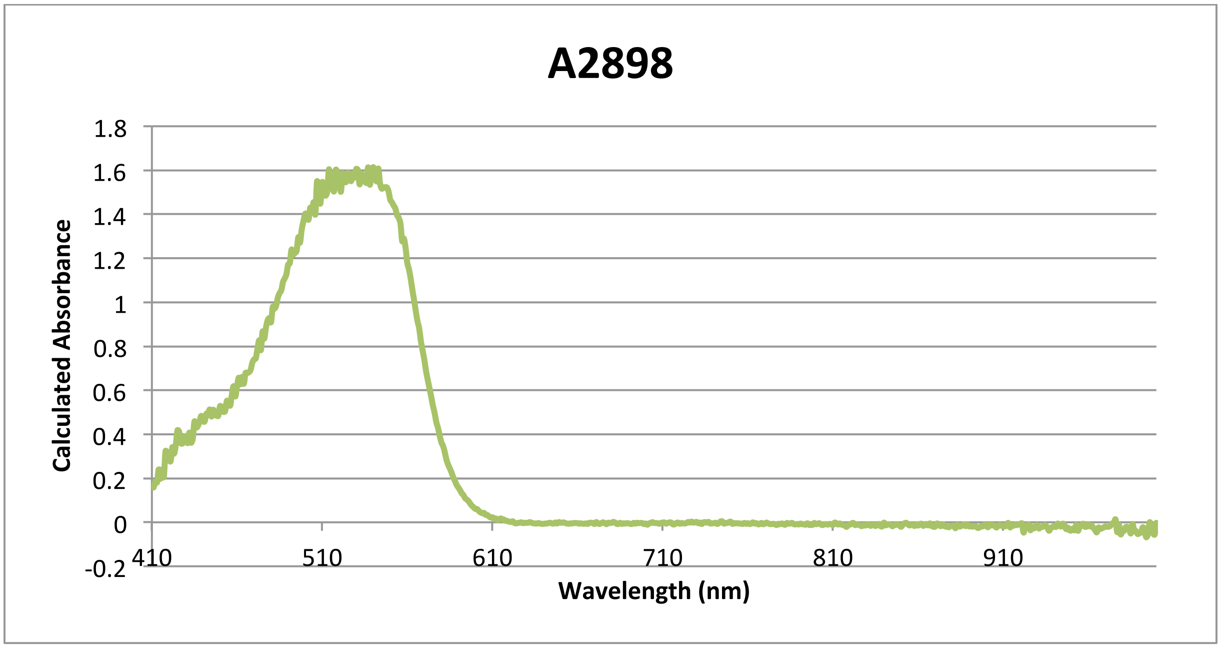



Figure 8. Absorbance data of Technicolor test dye strip taken 4/1/2015. Film samples from the George Eastman House, Box 12, Andreas Collection. Data and chart created by Bill Ryan and Melissa Sagen.

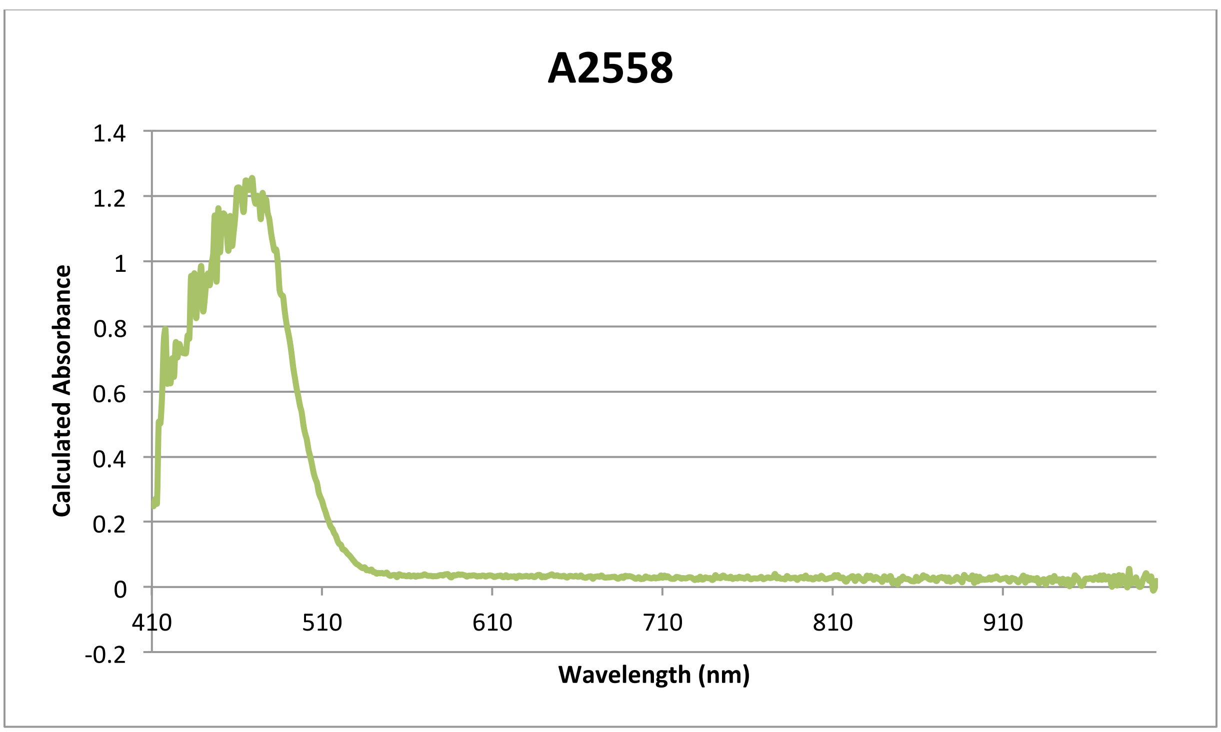


Figure 9. Transmittance data of Technicolor test dye strip taken 4/1/2015. Film samples from the George Eastman House, Box 6, Andreas Collection. Data and chart created by Bill Ryan and Melissa Sagen.

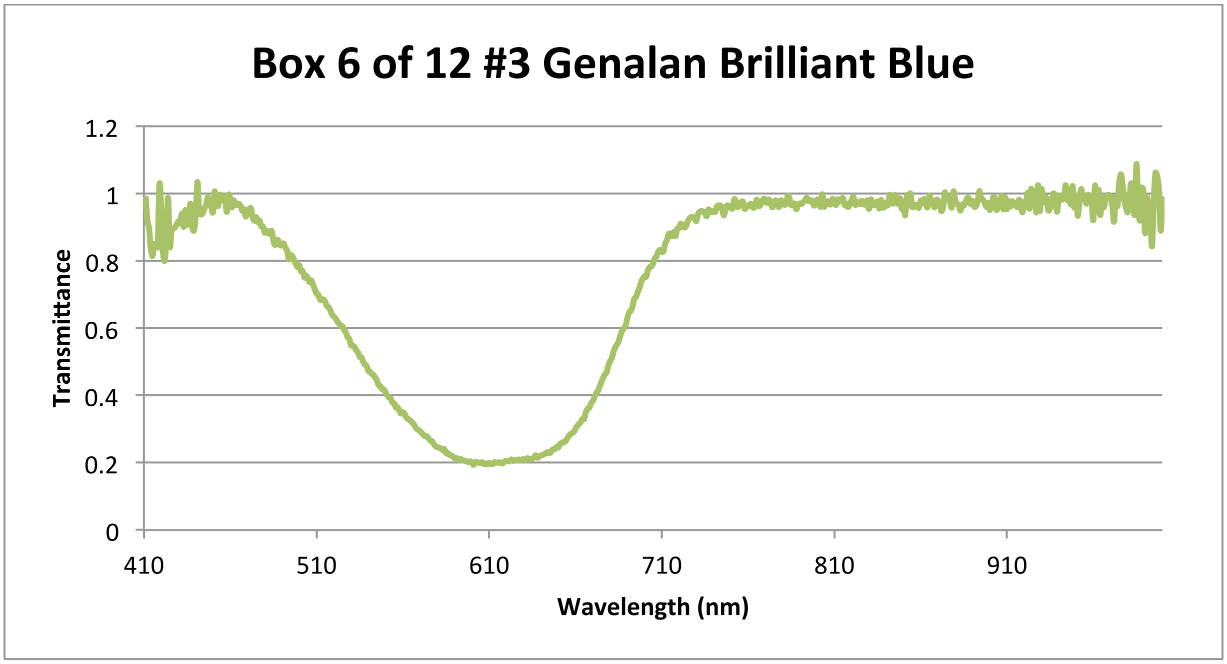



Figure 10. Transmittance data of Technicolor test dye strip taken 4/1/2015. Film samples from the George Eastman House, Box 12, Andreas Collection. Data and chart created by Bill Ryan and Melissa Sagen.

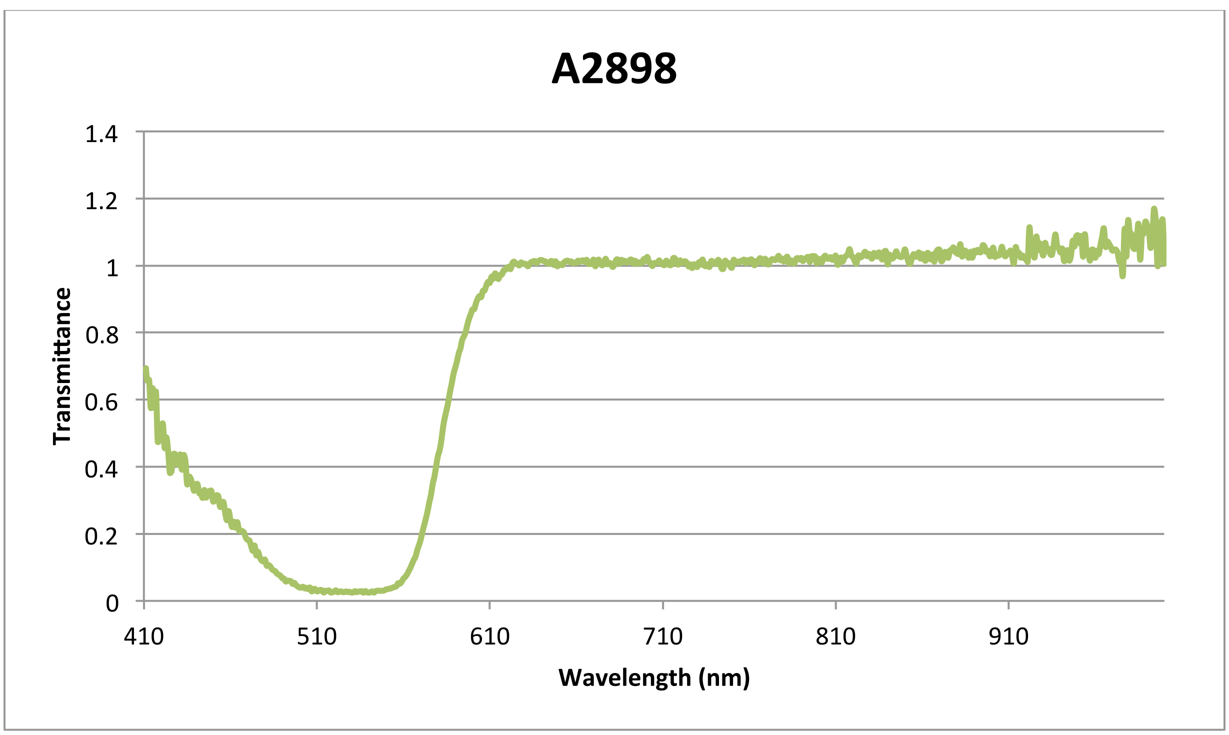


Figure 11. Transmittance data of Technicolor test dye strip taken 4/1/2015. Film samples from the George Eastman House, Box 6, Andreas Collection. Data and chart created by Bill Ryan and Melissa Sagen.

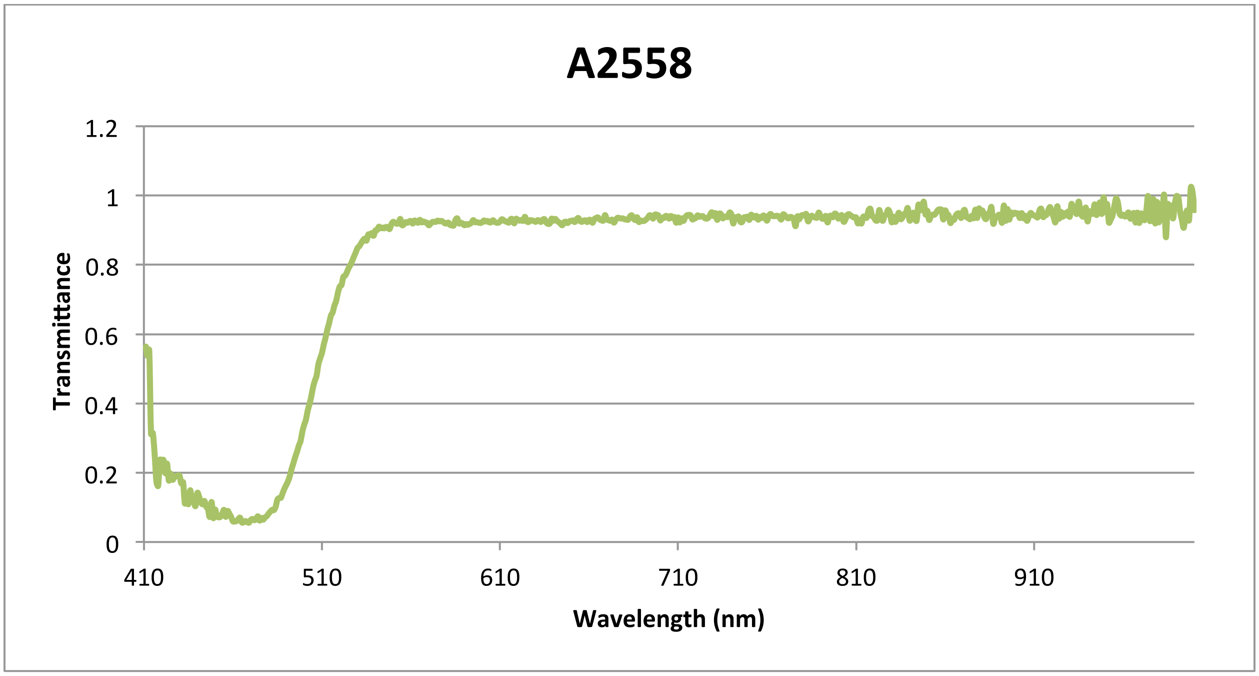



Figure 12

The web link to the raw data collected

file:///C:/Users/Mel/Downloads/Film%20Data%20Analysis_%20Absorbance%20and%20Transmittance_%20April%202,%202015.htm

Appendix 4 Absorbance of Technicolor Film Reels

Figure 13. Absorbance data of Technicolor film reel taken 4/29/2015. Film samples from the George Eastman House, 95:0194:1. Data and chart created by Bill Ryan and Melissa Sagen.

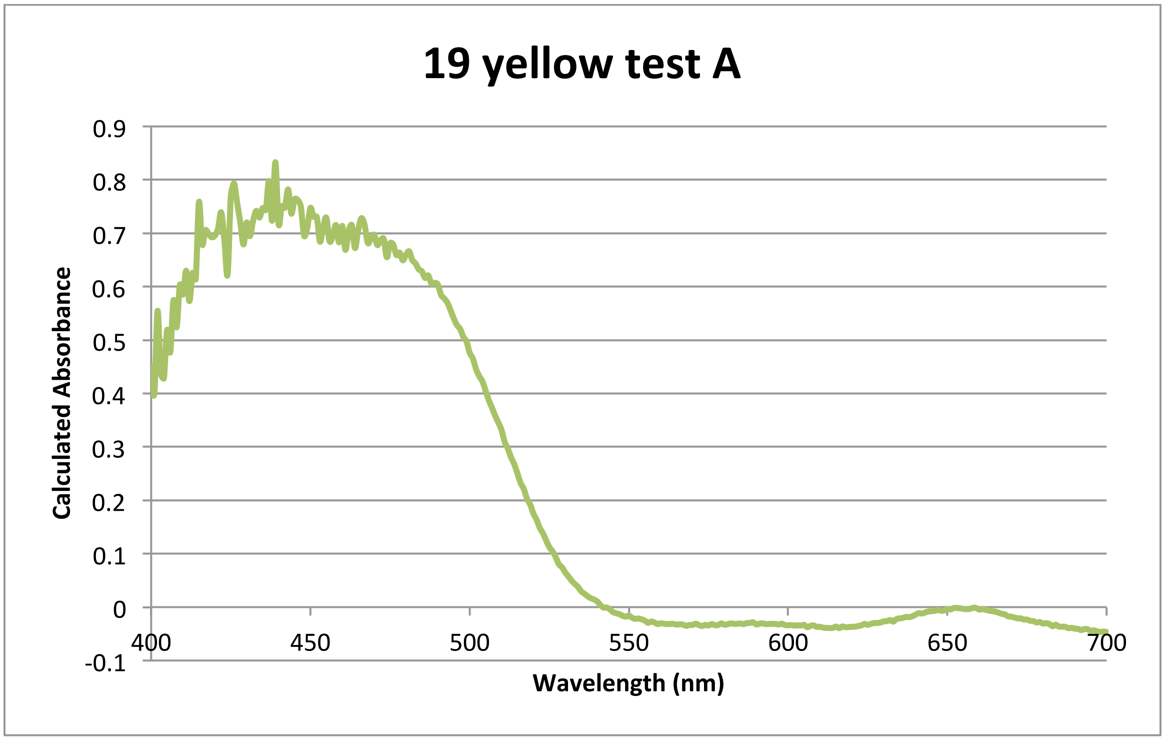
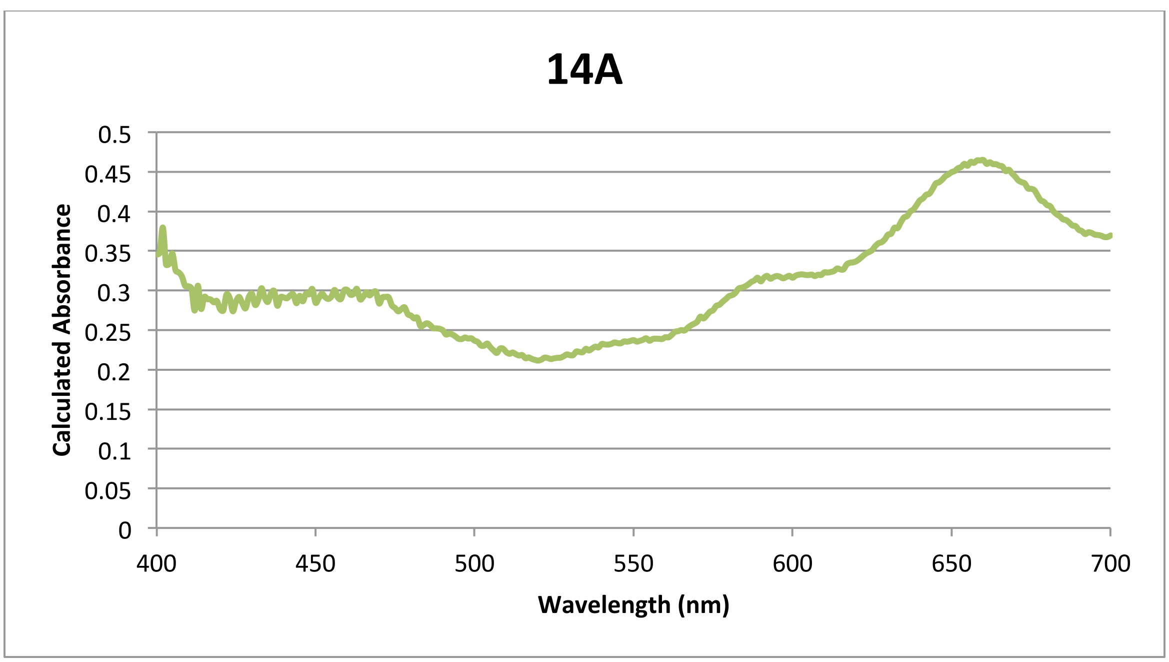



Figure 14. Absorbance data of Technicolor film reel taken 4/29/2015. Film samples from the George Eastman House, 1.98:2079:1, Martin Scorsese Collection. Data and chart created by Bill Ryan and Melissa Sagen.



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