Article: Technical Investigation of the Effects of Light and Humidity on Diazotypes
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Technical Investigation of the Effects of Light and Humidity on Diazotypes

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ABSTRACT

Diazotype prints are known to exhibit significant color change over time, which presents concerns for prints held in museum collections that may enter the exhibition rotation. The nature of the color change is not well understood, although it is presumed that both light exposure and environmental factors play a role. Given the relatively small amount of technical study on this subject, research was carried out at The Metropolitan Museum of Art to better understand how these environmental factors influence change in diazotypes. As student interns, Margaret Wessling and Greta Glaser carried out separate experiments on historic and contemporary diazotype samples leading up to the important exhibition of Francesca Woodman's mammoth diazotype collage, *Blueprint for a Temple*. The experiments focused on the effects of light and humidity on color change in the diazotype samples, quantified by color measurements with a spectrophotometer. Microfade testing was performed on the historic and contemporary samples to determine whether results varied when light was isolated as the factor of change. Finally, color and environmental monitoring were performed on *Blueprint for a Temple* before and after exhibition, and the real-time data were compared with the experimental results.

1. INTRODUCTION TO THE PROJECT

Francesca Woodman's collaged artwork *Blueprint for a Temple* was on display at the Metropolitan Museum of Art (Met) from February to August of 2012. The work stands 14 feet tall and 9 feet wide, and comprises 29 separate diazotype prints adhered together onto a secondary paper backing (fig. 1). *Blueprint for a Temple* was shown as part of an exhibition of contemporary photography titled *Spies in the House of Art*, which explored the ways art museums influence artists and art-making. This exhibition marked the first time that the Met had shown the work since its acquisition in 2001 and coincided with *Francesca Woodman*, a retrospective exhibition at the Guggenheim Museum (organized by the San Francisco Museum of Modern Art). The conservation and exhibition

Fig. 1 Francesca Woodman, *Blueprint for a Temple*, 1980, diazotype collage, 440 x 282.4cm, Metropolitan Museum of Art, 2001.737. Courtesy of George and Betty Woodman.

of Woodman's *Blueprint for a Temple* proved to be an ideal opportunity to conduct research on the stability of diazotypes. Existing research performed by Dana Hemmenway at the Met in 1996 laid the groundwork for experiments that would further illuminate the preservation concerns related to diazotypes. Hemmenway's research, published in *Topics in Photographic Preservation* Volume 15, details the chemistry of diazotypes as well as Francesca Woodman's working practice.

1.1 HISTORY AND CHEMISTRY OF DIAZOTYPES PAPERS

The diazotype process is known by several names including diazotype, ozalid, and whiteprint, and can be found in many colors ranging from magenta, maroon, brown, yellow and violet to black or blue. The most common substrates are fiber-based papers, but diazotype can also be printed on tracing cloth, vellum, and synthetic supports such as polyester. The diazotype was first introduced as the primuline process in 1890, but did not become a commercially viable process until 1923 when the German company Kalle & Co. issued their first Ozalid papers (Price 2010, 198). The dry diazotype manufacturing process ensures that little to no dimensional change occurs in the support, making it an ideal 1:1 copying technology for architectural drawings. Consequently, diazotypes largely replaced blueprints by the mid-1950s (Price 2010, 199).

This photographic process relies on the light sensitivity of an azo (aniline) dye and its reaction with a phenol or naphthol coupling agent to create a monochrome image on a white ground. Both the dye and the coupling agent can have an effect on the final color of the print, though the dye is mostly responsible. To date some 2000 azo dyes used in diazotype manufacture have been identified, making dye-coupling combinations practically innumerable (Kissel 2009, 37). Most diazotypes are made by a direct positive process in which the azo dye is destroyed or deactivated by photodecomposition (Eq. 1). During development, an acid stabilizer is neutralized by ammonia vapors and the coupler is allowed to react with the surviving dye molecules (Eq. 2). Following processing, irregularly-shaped clouds of dye particles can be seen in the paper support under low magnification.

Equation (1): Diazo compound decomposition due to sensitivity of light

$$\underset{\text{diazonium salt}}{[R\text{-}N{=}N]^{+}X^{-}} \xrightarrow[H_2O]{h\nu} \underset{\text{phenol}}{R\text{-}OH} + N2 + H^{+}$$

(Adapted from Dinaburg 1964, p. 49)

Equation (2): Azo dye formation as a result of reaction with phenolic substances

$$\underset{\text{diazonium salt}}{[R\text{-}N{=}N]^{+}X^{-}} + R'\text{-}O^{-} \rightarrow \underset{\text{azo dye}}{R\text{-}N{=}N\text{-}R'\text{-}OH} + X^{-}$$

(Adapted from Dinaburg 1964, p. 49)

1.2 DETERIORATION CONCERNS

Several circumstances may contribute to the deterioration of diazotype prints. Perhaps the most disheartening and well-known vulnerability of diazotypes is continued sensitivity to light and subsequent color change of the image. In 2002 Jennifer Koerner and Karen Potje performed fading tests on several historic diazotype samples at the Canadian Center for Architecture. Their tests concluded that subtle variations during the processing steps of diazotypes may cause widely varying reactions to light exposure (Koerner and Potje 2002). Dry processing has the unfortunate consequence that the papers retain all decomposition products, including those of the dye compound, the coupler, the acid stabilizer, and any degradation products of aging ligneous and cellulosic materials (Hawken 1960, 172). The phenol couplers can also oxidize and turn yellow or brown with time, a process that is exacerbated by light exposure and high humidity (Koerner 2002, 18). Additionally, most diazotype papers tend to be manufactured using lower quality materials, such as wood pulp (Price 2010, 199). The continued degradation of any of these materials may also cause the background of a diazotype print to change with time.

2. EFFECTS OF LIGHT ON HISTORIC DIAZOTYPE PAPERS

In 2011 Met Graduate Intern Margaret Wessling conducted a study of the effects of light on historic diazotype papers using samples from the Met's Photograph Conservation Department study collection. The goal of this experiment was to track the color shifts that diazotypes experience during quantifiable light exposure, and to compare them to diazotypes kept in the dark. A secondary goal was to test the effect of sealed packages in light and dark environments.

2.1 DESIGN

Twelve samples of fully processed and naturally aged blue diazotype paper were exposed to four different lighting conditions: 1) intense light exposure in a sealed package with UV-filtering acrylic; 2) intense light exposure without packaging or acrylic; 3) in a dark box in a sealed package; and 4) in a dark box without packaging. The historic sample diazotype paper contained no image, however there were areas of different density and intensity of color throughout the roll. Samples were cut from the most uniform areas of the paper into squares of 4 x 4 inches. The samples were V-hinged to 11x14 inch non-buffered Museum Rising Board mounts with Japanese paper and wheat starch paste using a technique to minimize moisture exposure. The samples were then covered with window mats (also of non-buffered Museum Rising Board), with window openings of 3 x 3 inches. All window mats were hinged to their respective back mats with pressure-sensitive linen tape with acrylic adhesive.

Six of the diazotype samples were sealed in packages behind Acrylite® OP2 UV-filtering acrylic sheets, and six were left unsealed and unglazed. For the sealed packages, a single sheet of desiccated, four-ply Rising Museum Board was placed behind the mounting board. The matboard was desiccated by placing it in a dry-mount press for twenty to thirty minutes, then immediately removed and placed in the sealed packages. The backs of the packages were covered with a sheet of Marvelseal® barrier film, which was trimmed, folded, and fused with heat to the sides of the sealed package stack. All four sides were then covered with 3M Scotch #001 tape. The window mats of the unsealed packages were secured with polyethylene strapping.

Three sealed and three unsealed diazotype samples were exposed to light on display shelves in the Photograph Conservation lab at the Met for 37 days with an average of 75 footcandles. The light source was tungsten lighting identical to that used in the photography galleries at the Met. The total light exposure calculated was 65,700 foot-candle hours. Concurrently, the other six samples were kept in a Solander box in the dark in the same room. This is equivalent to roughly two and a half years of exhibition exposure at 10 footcandles for 12 hours a day, six days per week.

2.2 RESULTS

Color measurements were taken on all of the diazotype samples using a standard Mylar template with five measurement sites (fig. 2). Four sites were located inside the area of the window mat opening, with one sample in each of four evenly spaced quadrants. The fifth area was located in the margin covered by the window mat. Color shifts were tracked using an X-Rite 968 0°/45° spectrophotometer, using X-Rite Color Master 5.1.1 software, employing the CIE L*a*b* 1976 color space to evaluate the data.

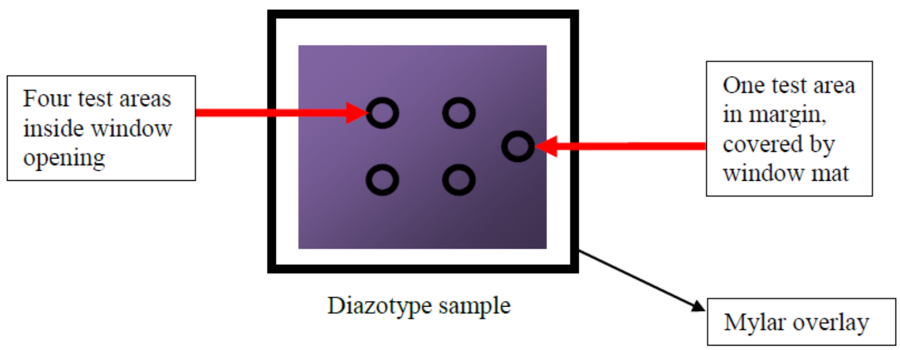

Fig. 2. Map of target areas for spectrophotometer measurements.

The samples exposed to light showed significantly more color change than the samples kept in the dark. However, there was a surprising lack of variation between sealed and unsealed packages exposed to light. In fact, the samples in sealed packages showed slightly more change than the samples that were left open to the ambient conditions. Change calculated for samples kept in the dark was also higher than expected, although the sealed package samples showed less change on average than the unsealed samples.

The CIE L*a*b* data for this experiment shows conclusively that all samples exposed to light experienced color shifts toward the yellow/red region of the color space, as well as overall lightening (Table 1). This suggests two mechanisms that may be at work: loss of image dye density and yellowing of the paper support. Sites measured in the margins of the light-exposed samples did not exhibit this type of color change.

The color change data for the samples kept in the dark is not as conclusive as for the samples exposed to light. Most dark samples exhibited a small shift toward the blue end of the color space. Most samples also exhibited very slight darkening. These results are significantly small and could be attributed to user or instrument error.

Table 1: Color Data Collected on Historic Diazotype Samples Before and After Aging

Environment	Measurement	Site	L*	a*	b*	ΔL*	Δa*	Δb*	ΔE*
Air, Dark	Average Final	1	36.25	24.26	-19.28	-0.09	0.09	-0.51	0.52
Air, Dark	Average Final	2	36.57	24.02	-19.10	-0.10	0.14	-0.53	0.56
Air, Dark	Average Final	3	35.64	24.43	-19.66	-0.23	0.07	-0.59	0.64
Air, Dark	Average Final	4	35.19	24.16	-19.97	-0.15	0.11	-0.60	0.63
Air, Dark	Final	5 margin	35.50	24.47	-19.58	-0.13	0.10	-0.56	0.58
Air, Light	Average Final	1	36.42	27.09	-17.40	3.20	2.56	1.41	4.34
Air, Light	Average Final	2	36.13	26.87	-17.61	3.16	2.55	1.38	4.29
Air, Light	Average Final	3	36.02	27.18	-17.68	3.01	2.51	1.30	4.13
Air, Light	Average Final	4	36.46	26.91	-17.27	3.04	2.42	1.31	4.10
Air, Light	Final	5 margin	33.14	24.85	-19.53	0.04	0.44	-0.05	0.45
Package, Dark	Average Final	1	40.79	22.62	-20.07	-0.08	0.19	-0.39	0.44
Package, Dark	Average Final	2	41.21	22.50	-19.79	0.07	0.16	-0.41	0.44
Package, Dark	Average Final	3	42.22	22.10	-19.61	-0.11	0.15	-0.33	0.38
Package, Dark	Average Final	4	41.86	22.33	-19.62	-0.15	0.14	-0.37	0.43
Package, Dark	Final	5 margin	41.60	22.32	-19.35	-0.17	0.05	-0.25	0.31
Package, Light	Average Final	1	50.80	23.15	-15.01	3.33	0.86	3.50	4.91
Package, Light	Average Final	2	50.36	23.48	-14.94	3.09	0.90	3.41	4.69
Package, Light	Average Final	3	50.96	23.10	-14.89	2.93	0.83	3.20	4.42
Package, Light	Average Final	4	51.09	23.23	-14.71	3.21	0.83	3.17	4.59
Package, Light	Final	5 margin	48.02	22.61	-17.64	0.03	0.11	-0.22	0.25

3. EFFECTS OF LIGHT AND HUMIDITY ON CONTEMPORARY DIAZOTYPE PAPERS

In 2012 Met Graduate Intern Greta Glaser studied the combined effects of light and humidity on contemporary diazotype papers that were donated by The Better Image®. The primary goal of this study was to build upon the data that Wessling collected a year prior by adding a second variable: humidity.

3.1 DESIGN

Contemporary diazotype paper, Blueprint Blueline X-Fast Speed by Océ– Imaging Supplies, was printed with a 4-step wedge multiple times to create 45 identical samples. The samples were suspended in large glass jars conditioned with glycerol/water mixtures to create eight, separate artificial environments: two at 30% relative humidity, two at 50%, two at 70%, and two at 90% (fig 3). One of each artificial environment was aged in continuous light and one in the dark for approximately 40

Fig. 3. Diazotype samples are suspended in glass jars with glycerol mixtures to control environmental conditions.

days. The samples aged in light received about 72,000 footcandle hours of exposure using the same lighting system in Wessling's experiment. This is equivalent to roughly two years of exhibition exposure at 10 footcandles for 12 hours a day, six days per week.

Prior to artificial aging, a trial using the glycerol/water mixture was carried out to ensure that the design would maintain the desired conditions for the duration of the experiment. A data logger was suspended in a sealed jar for four days with the proportion of glycerol to maintain a 70% relative humidity environment. The data collected from this trial indicated that the humidity level was sufficiently consistent and that the experiment could proceed using this design. Each glycerol mixture was weighed on separate dishes made from 0.001 mil Mylar®. Table 2 below shows the amount of glycerol to produce the artificial environments.

Table 2: Glycerol proportions used to control microenvironments

Desired %RH	Glycerol (by %W)	Glycerol needed in a 5g mixture (g)	Water needed in a 5g mixture (g)
30	89	4.45	0.05
50	n/a	n/a	n/a
70	64	3.20	1.80
90	33	1.65	3.35

3.2 RESULTS

Like Wessling's data, color measurement results were interpreted using the CIE L*a*b* 1976 color space. Changes in L*a*b* values and Delta E were calculated for each of the samples. The most notable visible change is that all of the samples, except some in the control group, shifted toward yellow with the greatest change occurring in those samples which were aged in 90% and 70% relative humidity in the light. The majority of the samples also shifted slightly toward green and away from red with two exceptions: the highest density areas aged in the dark generally shifted toward red, likely a result of the color "warming" with the overall yellowing effect.

Almost all of the samples lightened; those samples aged in the light showed the most change. The control group is the only sample set that, on average, darkened instead, although no control sample experienced a ΔL* greater than 1, which is considered a noticeable change. Table 3 below summarizes the data gathered for this experiment by presenting the averages of the site readings for each environment. Site "A" refers to highlight (D-Min) areas, "D" to maximum density (D-Max) areas, and "B" and "C" respectively to mid-tones (D-Mid) between the D-Min and D-Max areas.

Table 3: Color Data Collected on Contemporary Diazotype Samples Before and After Aging

Environment	Measurement	Site	L*	a*	b*	ΔL*	Δa*	Δb*	ΔE*
Control	Average Final	A	42.77	17.12	-42.38	0.14	-0.06	-0.04	0.25
Control	Average Final	B	57.91	8.02	-31.99	-0.04	-0.08	-0.03	0.24
Control	Average Final	C	82.88	-0.09	-7.46	-0.09	-0.18	0.19	0.35
Control	Average Final	D	90.85	0.02	2.39	-0.25	-0.15	0.38	0.53
Dark, 30%	Average Final	A	42.30	17.11	-42.39	0.07	-0.46	0.19	0.52
Dark, 30%	Average Final	B	57.91	8.15	-32.33	0.03	-0.30	0.12	0.38
Dark, 30%	Average Final	C	82.98	0.01	-7.62	-0.01	-0.15	0.18	0.29
Dark, 30%	Average Final	D	91.13	0.16	1.88	-0.07	-0.08	0.20	0.26
Dark, 50%	Average Final	A	42.67	17.81	-42.38	0.37	0.10	0.30	0.57
Dark, 50%	Average Final	B	57.92	8.85	-32.45	0.32	0.07	0.29	0.65
Dark, 50%	Average Final	C	83.71	0.12	-6.99	0.25	-0.17	0.65	0.76
Dark, 50%	Average Final	D	91.23	0.12	2.19	-0.08	-0.17	0.67	0.70
Dark, 70%	Average Final	A	42.58	18.72	-42.15	0.64	0.76	0.77	1.31
Dark, 70%	Average Final	B	57.40	9.71	-32.41	0.48	0.59	0.77	1.25
Dark, 70%	Average Final	C	83.30	0.23	-6.82	0.15	-0.07	1.10	1.14
Dark, 70%	Average Final	D	91.00	0.09	2.63	-0.10	-0.19	1.09	1.11
Dark, 90%	Average Final	A	42.99	19.68	-40.38	1.12	1.83	2.39	3.27
Dark, 90%	Average Final	B	57.03	11.38	-31.53	-0.36	2.47	1.41	2.96
Dark, 90%	Average Final	C	82.89	-0.22	-5.21	-0.52	-0.46	2.23	2.35
Dark, 90%	Average Final	D	90.93	-0.39	5.02	-0.15	-0.68	3.40	3.47
Light, 30%	Average Final	A	43.35	16.83	-40.92	1.24	-1.04	2.00	2.58
Light, 30%	Average Final	B	58.95	8.05	-30.49	1.72	-0.91	2.70	3.34
Light, 30%	Average Final	C	85.91	0.40	-3.88	1.32	0.25	2.34	2.71
Light, 30%	Average Final	D	91.92	0.58	3.32	0.74	0.35	1.63	1.84
Light, 50%	Average Final	A	43.58	16.76	-41.22	1.04	-0.71	1.48	1.97
Light, 50%	Average Final	B	60.45	7.34	-29.56	1.43	-0.62	2.26	2.78
Light, 50%	Average Final	C	85.43	0.29	-4.22	1.27	0.16	2.57	2.88
Light, 50%	Average Final	D	91.77	0.48	3.65	0.67	0.23	2.02	2.14
Light, 70%	Average Final	A	44.97	17.27	-39.88	1.74	0.27	2.38	3.06
Light, 70%	Average Final	B	61.76	7.51	-27.58	1.96	0.05	3.38	3.98
Light, 70%	Average Final	C	85.27	-0.03	-2.67	1.22	-0.13	4.10	4.29
Light, 70%	Average Final	D	91.44	0.04	5.62	0.30	-0.16	3.77	3.79
Light, 90%	Average Final	A	46.18	14.98	-36.34	3.32	-2.32	6.12	7.38
Light, 90%	Average Final	B	61.41	5.41	-23.23	3.38	-2.88	9.04	10.09
Light, 90%	Average Final	C	85.03	-1.18	4.37	0.93	-1.22	11.00	11.11
Light, 90%	Average Final	D	89.26	-0.33	11.67	-1.78	-0.52	9.87	10.05

4. MICROFADE TESTS OF HISTORIC AND CONTEMPORARY DIAZOTYPE PAPERS

The historic and contemporary diazotype papers were both examined using a microfading-tester (MFT). The Met's MFT is based on the original design by Paul Whitmore with a fiber optic cable and a xenon arc lamp light source. The light is filtered in the machine to remove UV and IR wavelengths, simulating museum gallery lighting. Reflectance data is captured through a spectrophotometer and spectral data is processed using Spec32 software and translated to the

CIE L*a*b* color space. The measurement area of the machine is a few hundred nanometers, so a faded spot is not readily visible to the naked eye.

4.1 DESIGN

The benefit of microfading is the ability to look at the effect of light in relative isolation from other environmental phenomena. As the instrument captures color information it generates real-time Delta E values. Testing is begun by fading samples of blue wool standards 1, 2, and 3 (BW1, BW2, BW3) to be used as standards for data comparison. Fading curves falling in the region above BW1 are considered to have very high sensitivity to light. Curves falling between and below BW2 and BW3 are considered to have correspondingly lower light sensitivity.

One sample of the darker density historic diazotype paper was tested, and control sample #1 of the contemporary paper was tested at four different densities. The samples were tested for twenty minutes with the software logging new color measurements every thirty seconds for a total of 41 total readings including the beginning reference reading.

4.2 RESULTS

The historic sample paper initially showed light stability in the vicinity of BW3, but as the test progressed beyond two minutes the sensitivity increased to BW2. A similar effect was observed with the contemporary sample where all but the lightest density areas exhibited increasing light sensitivity. The fading of the blue wool standards occurs as a curve that has an initial spike and then begins to plateau. The diazotype papers, however, show a nearly straight progression suggesting the dyes continuously fade and could eventually exhibit light sensitivity at or above BW1.

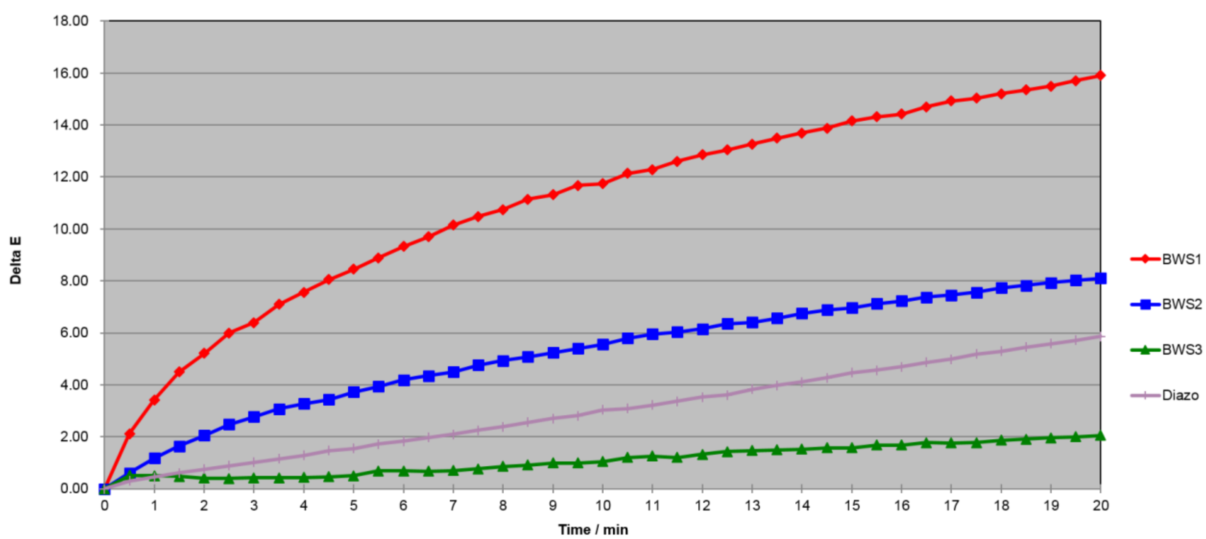

Fig. 4. Historic sample paper, D-Max only, twenty minute test

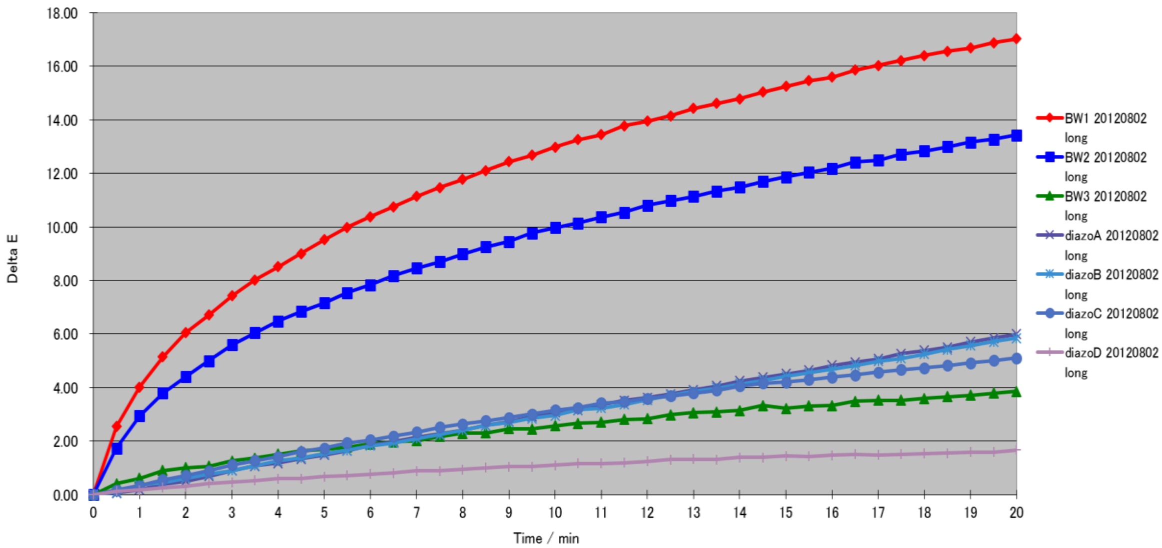

Fig. 5. Contemporary sample paper from the control group read at multiple densities, twenty minute test

5. ENVIRONMENTAL AND COLOR MONITORING OF *BLUEPRINT FOR A TEMPLE*

The exhibition of Francesca Woodman's *Blueprint for a Temple* at the Met in 2012 provided the valuable opportunity to compare real-time color measurements to the experimental results. Katherine Sanderson completed color readings of the work before and after exhibition using the same X-Rite 968 spectrophotometer. She created custom Mylar templates to sample a variety of areas on the collage. Figure 6 shows the location of six Mylar templates, each with between four and six measurement sites representing a range of image densities and tonalities. The collage was displayed for seven months in average gallery conditions of 72 degrees Fahrenheit and 50% relative humidity with an average light level of 6.5 footcandles. The total light dosage calculated was 13,885 footcandle hours. The object was displayed behind a two-part acrylic bonnet. The acrylic glazing was not UV filtering, however the halogen lights in the galleries were filtered and readings taken in the gallery indicate no UV component in the output.

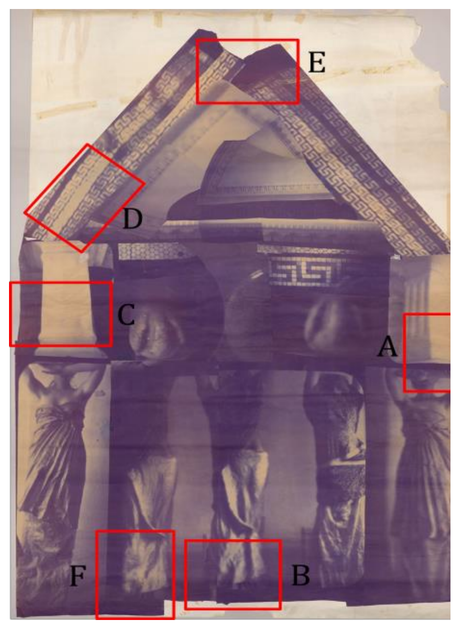

Fig 6. Locations for sites of spectro-photometric readings on Francesca Woodmans's *Blueprint for a Temple*. In all, there were 31 measurement sites.

5.1 RESULTS

The real-time color readings were consistent across all reading sites with regard to the nature of the color change. Overall, there were shifts towards yellow and red (positive a* and b* values), as well as lightening (positive L* values). The high and mid-density areas showed about the same amount of a* and b* shifts, with the exception of two sites on one piece of the collage that showed a greater amount of change (A_D-Max and A_D-Max_Stain). Because the collage is composed of many separate diazotype pieces, it is possible that there were variations in the processing of the many prints, resulting in variable sensitivity to exhibition conditions. The minimum density areas showed approximately half to a third as much color change as the other sites, which correlates with data collected in the microfading tests.

Table 4: Color Data Collected on *Blueprint for a Temple* Before and After Exhibition

Template	Measurement Site	Measurement	L*	a*	b*	ΔL*	Δa*	Δb*	ΔE*
A	D-Max	Final	34.28	20.69	-19.55	1.15	0.96	1.58	2.18
A	D-Max (stain)	Final	36.86	16.42	-20.74	1.64	0.95	1.95	2.72
A	D-Mid	Final	55.97	12.28	-2.94	1.96	0.86	1.61	2.68
A	D-Min	Final	78.36	6.33	21.86	0.27	-0.02	0.41	0.49
B	D-Max1	Final	36.09	19.48	-16.86	0.98	0.72	1.28	1.77
B	D-Max2	Final	34.52	19.85	-18.91	0.61	0.59	1.11	1.40
B	D-Mid1	Final	49.42	15.22	-9.96	1.62	0.71	1.81	2.53
B	D-Mid2	Final	47.09	14.53	-13.55	0.34	0.78	0.98	1.30
B	D-Min1	Final	73.82	5.64	13.34	0.68	0.34	0.82	1.12
B	D-Min2	Final	74.11	5.02	12.50	0.85	0.25	0.99	1.33
C	D-Max1	Final	35.35	20.92	-19.24	0.89	0.51	1.47	1.79
C	D-Max2	Final	41.75	18.91	-12.12	1.13	0.97	1.57	2.16
C	D-Max3	Final	44.96	20.80	-9.89	1.27	0.65	1.51	2.08
C	D-Min1	Final	79.08	5.42	20.56	0.30	0.07	0.54	0.62
C	D-Min2	Final	79.51	5.83	20.00	0.54	-0.05	0.47	0.72
D	D-Max	Final	42.23	18.29	-14.80	0.19	0.38	1.29	1.36
D	D-Mid	Final	58.41	10.43	-4.74	0.92	1.13	1.46	2.06
D	D-Min1	Final	78.37	4.11	17.73	0.32	0.04	0.40	0.51
D	D-Min2	Final	80.37	4.81	19.94	0.22	0.25	0.52	0.62
E	D-Max1	Final	35.72	21.13	-18.45	0.78	0.32	1.41	1.64
E	D-Max2	Final	40.96	21.77	-12.77	0.62	0.76	1.32	1.64
E	D-Mid1	Final	54.03	14.97	-4.46	0.84	0.39	1.15	1.48
E	D-Mid2	Final	67.13	8.67	7.34	0.81	0.21	1.16	1.43
E	D-Mid3	Final	52.55	17.57	-7.46	0.74	0.64	1.49	1.78
E	D-Min1	Final	81.19	4.72	22.49	0.13	0.13	0.57	0.60
E	D-Min2	Final	74.64	7.25	16.82	0.79	0.01	0.99	1.27
F	D-Max	Final	35.09	20.57	-18.49	1.47	0.73	1.47	2.20
F	D-Mid	Final	42.78	16.26	-13.27	0.60	0.86	1.04	1.48
F	D-Min	Final	72.13	6.37	13.93	0.88	0.21	0.92	1.29
F	D-Max (stain)1	Final	34.04	17.45	-19.99	0.64	0.90	0.89	1.42
F	D-Max (stain)2	Final	43.70	13.06	-13.99	1.50	0.74	1.59	2.31

D-Max refers to maximum density, D-min refers to minimum density (highlights), and D-Mid refers to medium density.

6. DISCUSSION AND CONCLUSIONS

The consistent finding amongst all of the collected color data was positive shifts in b* and a* values, both for diazotype samples that were exposed to light and ones kept in the dark. We can therefore make the general conclusion that blue diazotypes become warmer in tonality as a result of light, humidity exposure, and age. This conclusion is consistent with historic reports that blue dyes lose color stability while paper supports and additives yellow with light exposure, resulting in a shift towards an overall purple color.

Comparing the historic diazotype paper samples to the contemporary samples informs how the process of discoloration unfolds. The historic samples in this investigation experienced more color change in a roughly equal amount of light exposure than the contemporary samples exposed to common ambient museum conditions (50% relative humidity and 70 degrees Fahrenheit). The historic papers also experienced greater shifts towards red, while the contemporary papers experienced greater shifts towards yellow. This suggests that the paper support and additives are the first components of diazotypes to begin the discoloration process. Later on in the life of the print the dyes begin fading, which in combination with the yellowing of the support appears as overall reddening. The microfading results also suggest that diazotype discoloration does not plateau in the manner of the dyes used for Blue Wool, but may continue more steadily to the point of gross image loss. A longer microfading test would help to confirm or deny this; it may be the case that fading would plateau at a later point.

The largest color shifts calculated in Glaser's experiment were in the mid tones and highlights and not in the darkest areas where the paper support is least visible. The shifts towards yellow were significantly larger than those on the other color axes. This underscores the theory that the paper supports yellowed while the dyes stayed relatively intact. Glaser's experiment also revealed how detrimental elevated humidity can be, especially when paired with light exposure. A relative humidity level of 90% can significantly change the color of the paper, even in the dark. Samples exposed to these conditions in the dark showed Delta E values between 3.0 and 3.5 over the course of only 40 days. High relative humidity combined with light exposure produced the significantly elevated result of Delta E values between 7.4 and 11.0. Results for medium and maximum density samples in the light at 90% relative humidity showed negative a* values, indicating a shift toward green, away from red, paired with positive b* values, indicating significant yellowing. One possible explanation is that the blue azo dyes stayed relatively intact in comparison to the severe yellowing of the paper, which resulted in an overall measureable shift toward green. The green shifts were not seen to the same extent on the samples at 90% relative humidity in the dark. The data clearly shows that it is the combination of elevated relative humidity and light that is most deleterious to diazotypes.

Wessling's historic sample papers compared to Sanderson's real-time readings of maximum density sites in *Blueprint for a Temple* were relatively similar. Both the samples and the artwork showed overall lightening and shifts towards red and yellow. However, *Blueprint for a Temple* experienced a greater amount of change than was predicted from Wessling's experiment. The total light dosage from the experiment was five times the dosage of the Met's exhibition. The recorded average Delta E for *Blueprint for a Temple* was 1.5 (not taking into consideration the readings for area A that experienced significantly greater change), while the average Delta E for Wessling's samples was 4.5. This finding underscores the variability of the different diazotype dyes and their respective light and humidity sensitivities. It is also likely that other dye formulations have even greater sensitivity than the ones measured here and may change at a different rate than the papers examined in this study.

The observed general lightening and warming of all diazotypes tested in this investigation is consistent with historic reports that diazotype dyes lose color stability with time and their paper supports yellow with light exposure. Elevated humidity levels can be particularly detrimental, as is shown by the extent of the color change in the samples that were aged in high humidity, both in the light and in the dark. However, reducing the relative humidity below 50% does not offer significant additional benefit. While Wessling's experiment showed that sealed packages may not provide helpful protection during exhibition, future studies of diazotypes would benefit from testing other environmental factors such as temperature and pollutants. Also, it would be illuminating to switch Glaser's and Wessling's experimental set-ups to test the effects of humidity on aged samples and the effects of sealed and unsealed packages on fresh samples.

The authors recommend for institutions exhibiting diazotypes to closely monitor light and other environmental conditions and keep relative humidity close to or under 50%. Because diazotypes are monochromatic, it is possible to lower light intensity on display without sacrificing image legibility. The results of this investigation are not sufficient to indicate what chemical changes may be taking place, and given the variety of diazotype papers and dye combinations that were available on the market, the dye chemistry in the historic and contemporary papers is likely to be different. The complex chemistry of diazotypes may mean some papers are more stable than others, though proper precautions should always be taken to ensure that the aging process is allayed as much as possible.

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