Light Exposure to Sensitive Artworks during Digital Photography

Ben Blackwell

As more museums consider plans to digitize their collections, there have been concerns about the light levels required by digital scanning cameras. There has been little published on the subject, or indeed on exposure during conventional photography, but most museums follow guidelines governing light exposure during exhibitions, and since exposure follows the reciprocity law, it's easy to translate exposure during photography into its equivalent under gallery conditions.

Reciprocity

Bunsen and Roscoe's law, expressed as H = l x t = constant, implies that exposure, (H), at a high intensity for a short time (t), is the same as exposure at a low intensity (l) for a correspondingly longer time. 1000 lux for 10 seconds has the same effect as 10 lux for 1000 seconds. Or, as expressed by Stefan Michalski, "light effects are cumulative in a simple additive manner"[1] According to Michalski, a number of studies have upheld this principal as applied to light-sensitive materials, notably that conducted by Saunders and Kirby of the National Gallery of London[2]

Most photographers are familiar with the reciprocity law, on which equivalent exposures are based, and with the notion of reciprocity failure— the fact that some photosensitive materials don't respond as predicted at very short or very long exposures. These deviations are always in the direction of less effect, and aren't relevant to this discussion.

Museum policy for exhibition exposure

Most museums monitor the environment in which their collections are kept, and impose restrictions on the type and amount of light in the galleries, and on the length of exhibitions. These rules vary, but for works on paper, photographs, and other sensitive objects, five foot-candles or 50 lux is a common standard for gallery lighting..[3] This is quite dim for reading, working, or critical seeing.[4] Guidelines for exhibition length range from four to twelve weeks per year, six weeks being average.

In 1991 Karen Colby developed an exhibition policy for the Montreal Museum of Art, which has been widely cited.[5] Based on the British Blue Wool or International Standards Organization (ISO) standard[6] for light-induced fading, she dividing works into three categories of sensitivity and assigning exhibition light levels and durations accordingly. For Category 1 objects, the most fugitive, she recommends a maximum of 4 weeks exhibition per year at no more than 75 lux. This amounts to 12,000 lux/hours per year based on the 42 hour exhibition week at Montreal. The 75 lux standard is more liberal than some, but allows for some flexibility in exhibition design and the widespread skepticism about other institutions actually adhering to 50 lux for traveling exhibitions. At this level of exposure, works in this category would show just noticeable fading after 1.2 Mlux/hours, or 100 years of annual four-week exhibitions.[7] Works on paper assigned to categories 2 and 3 are allowed 100 lux for ten and

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[1] Stefan Michalski, Light Effects from Flashbulbs and Copiers, Abbey Journal, Volume 20, Number 6, Nov 1996 posted at http://palimpsest.stanford.edu/byorg/abbey/an/an20/an20-6/an20-607.html

[2] Saunders and Kirby, "Light induced damage: investigating the reciprocity principal," ICOM-CC Preprints, p. 87-90

[3] One foot-candle is defined as the intensity of light that falls upon a one foot square surface illuminated by a light source that equals one candle power, or candela. Lux is the metric measurement: the light on a one square meter surface one meter away from a source of 1 candela. One lux equals 0.0929 foot candles, or roughly 1/10 of a foot-candle. Therefore 5 foot-candles is about 50 lux.

[4] A bare 60-watt bulb in a large room produces 50 lux on a surface about 3 1/2 feet away; or aimed in a reflector desk lamp, about 6 feet distant. Colby notes that older viewers may have trouble seeing artwork exhibited at 50 lux.

[5] Karen M. Colby, "A Suggested Exhibition/Exposure Policy for Works of Art on Paper" available at http://www.lightresource.com/policy1.html

[6] The British Blue Wool Standards consist of eight dyed wool test specimens ranging from very fugitive (ISO 1) to very resistant (ISO 8). Each numbered specimen requires twice the exposure to exhibit the same degree of fading as the previous number. Each of Colby's categories incorporates three of the ISO levels and is based on the middle, i.e. Colby's Category 1 covers ISO categories 1, 2, and 3 and her recommendations for that category are based on objects with a light sensitivity of ISO 2.

[7] In practice most artifiacts aren't necessarily exhibited every year. 12 weeks exhibition every three years would result in the same exposure as 4 weeks every year.

twenty weeks respectively and fading would be noticed at 250 years (10 Mlux/hours) and 3500 years (300 Mlux hours).

It's clear that works on paper, considered among the most fragile and fugitive artworks, vary greatly in their vulnerability to light. However, Colby's Category 1 is a useful benchmark for assessing light exposure during photography. Category 1 includes materials that fall into the ISO levels 1, 2, and 3,but is based on the middle of that range. ISO 1 includes some objects that can tolerate virtually no light exposure at all, and these must be assessed individually as to whether they may be photographed or even viewed. Works this sensitive that haven't already faded to nothing represent a small percentage in most museum collections.

Types of Digital Cameras

Institutions considering direct digital capture of artworks have several options. Small works on paper can be scanned in flatbed scanners,[8], but for a wider range of objects, some sort of digital camera is required. Digital cameras come in several basic designs and a wide range of prices, any of which might find some application in museums, but institutions that are creating high resolution digital images adequate for all purposes, including fine print publication, are mostly using scanning cameras. A smaller number use high-end area-array cameras.

Area-array, or "chip" cameras, ranging from the familiar consumer digital cameras to professional models costing $30,000 or more, record images on a square or rectangular array of electronic sensors, usually charged-couple devices (CCDs). Models capable of "instantaneous" capture are able to photograph moving subjects, but are limited in resolution to a maximum of about 2000 X 3000 pixels. Moreover, since each sensor is dedicated to recording a single primary color of light— red, green or blue, the other two colors for each pixel have to be interpolated from data supplied by the adjacent sensors. "Three-shot" cameras avoid interpolation by taking separate exposures through red green and blue filters. These can capture monochrome images of moving subjects, but color images of stationary objects only. Maximum image size is the same as for high end one-shot cameras—2000 X 3000 pixels, producing an 18 MB file. Both types can be used with electronic flash, an advantage when cumulative exposure is a concern. Some institutions are using three-shot cameras, but because they're expensive, and produce a relatively small file, they're not as common as scanning cameras in museums and archives.[9]

Trilinear scanning cameras, or scan backs, incorporate three rows of sensors that travel across the image area. Because a relatively small number of CCDs record data across a large area, they produce the highest resolution images of any digital camera. The top end models cost $25,000 to $30,000, about the same as the high end chip cameras, but produce files up to around 500 MB. Mid-range models at a little more than half the price still render uninterpolated images of around 6000 X 8000 pixels, producing 24 bit RGB files of 140 MB. Since they work like a scanner inserted into a view camera in place of the film holder (or a medium-format film back in some smaller models), they require continuous light. Light requirements are higher than for shooting film under continuous light because during even a long scan, each data point is only exposed for a brief time (usually 1/8 second maximum), whereas during a long film exposure, the entire emulsion accumulates exposure at once. Exposure is greater than in a flatbed scanner, because the lights must be on for focusing and other adjustments as well as for the scan itself, though some of these operations can be carried out under reduced light.

Light Requirements of Digital Scan Backs

To determine the amount of exposure required by digital scan backs I've conducted tests at the Berkeley Art Museum using a Better Light Model Super 6K. This mid-range model is capable of capturing images of 6000 by 8000 pixels at standard resolution, or 9000 X 12000 pixels with minimal interpolation across the shorter dimension. Images can also be recorded at a number of lower resolutions, and this has a bearing on light exposure because scans become correspondingly shorter at lower resolutions. Scans can take from under a minute to 15 minutes or more, depending on light intensity, resolution and other camera settings. Time under the

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[E] Light exposure in scanners has been well addressed by Timothy Vitale's study: Light Levels Used in Modern Flatbed Scanners, found at http://www.rig.org/preserv/diginews/diginews2-5.html#technical

[9] There are other designs of digital cameras. Some, like the Jenoptik eyelike cameras, are being used for art reproduction.

lights for framing, focusing, prescans and adjustments vary even more, depending on the nature of the subject and setup and the operator's methods and skill. For flat copy work, we can assume between ten and 20 minutes under the lights, based on the variables mentioned.[10] Beside my own experience, observing other operators using similar equipment suggest 20 minutes as a reasonable maximum for flat copywork, though for production copying of similar size originals, times can be much shorter, and for complicated three-dimensional subjects, much longer.

The following tables show the exposure in lux/hours for captures at different resolutions for two actual copy setups, one with florescent light and one with tungsten.

Copy set up for 16X20 original, 2 Balcar florescent fixtures @ 6 feet. Illumination at copy stage 2056 lux (190 foot-candles)
Camera settings: aperture f11, ISO 400, line time 1/20 sec.

Pixel dimensions	File size	Scan time in minutes	Total time under lights	Exposure in lux/hours	Equivalent gallery time at 50 lux
12000X9000	309 MB	10	20 minutes	678 lux/hours	13 hours 42 minutes
8000 X6000	137.3 MB	6:40	16.40	570 lux/hours	11 hours 24 minutes
6000X4500	77.2 MB	5	15	516 lux/hours	10 hours, 32 minutes
4000X3000	34.3 MB	3.:20	13.:20	457 lux/hours	9 hours 14 minutes
2000X1500	17 MB	1:40	11.40	400 lux/hours	8 hours

Copy setup for 30X40 original, 2 Arri 1000 watt tungsten Fresnel instruments @ 12 feet 1647 lux (153 foot-candles)
Camera settings: aperture f11, ISO 400, line time 1/15 second

Pixel dimensions	File size	Scan time in minutes	Total time under lights	Total exposure in lux/hours	Equivalent gallery time at 50 lux
12000 X 9000	309. MB	13:20	28.20	777	15.hours 30 minutes
8000X6000	137.3 MB	8:53	23:53	646	13hours
6000 X 4500	77.2 MB	6:40	21:40	593	12 hours
4000 X 3000	34.3 MB	4:27	19.27	534	10 hours, 40 minutes
2000 X 1500	17 MB	3:20	18:20	502	10 hours

Line time, analogous to shutter speed and ISO settings, equivalent to film speed, are adjustable. Increasing either compensates for less light. However increasing line time results in longer scans time and increased noise, while higher ISO settings increase noise at a faster rate.[11] Most digital photographers prefer to work at the lowest ISO and the shortest line time light levels permit, for shorter scans and cleaner images.

Visiting other studios, I've generally encountered higher light levels than the c. 2000 lux I've been working with. With more light, scans are shortened, but other operations carried out under the lights are not. If total time under the lights were 20 minute, these exposures would result:

lux	foot-candles	time under lights	total lux/hours	equivalent at 50 lux
3000	280	20 minutes	900	18 hours
4000	372	20 minutes	1,333	26 hours 40minutes
5000	465	20 minutes	1,667	33 hours 30 minutes

[10] Scan backs from other manufacturers, Dicomed, Phase One, or Jobo, may vary in their scan times, but because the total time under the lights varies so much due to other factors, relatively small differences in scan time needn't be considered.
[11] Noise in digital images consists of anomalous pixels, usually appearing as random flecks of color in dark areas and looking something like film grain.

I haven't encountered any copy lighting higher than 5000 lux. Erik Landsberg at MOMA provided meter readings at one of their reprographic workstations, which translates to about 4600 lux. His estimate of 20 minutes as a maximum exposure time agreed with mine. The MOMA photographers are careful to minimize exposure, and cover the artwork during any interruption to the capture process.[12]

20 minutes exposure to 5000 lux would result in the equivalent of about four days in a 50 lux gallery. This is probably close to a maximum exposure for copywork. With the shorter scan times at 5000 lux, an experienced photographer probably wouldn't need 20 minutes with most subjects. In practice I think of most scans in terms of using up a day or two of exhibition time, or four days maximum.

Minimizing Exposure

It's worth remembering that not all, or even most works on paper fall into Category 1. Photographic prints for example include very durable toned black and white silver gelatin prints and very fugitive albumin and color prints. Photographers should be aware of the characteristics of the material, and adjust their techniques accordingly.

Some expert operators have developed low light methods involving multiple scans of the same image. Calculations would reveal whether this is advantageous, given reciprocity. Because some of the more vulnerable artifacts may not have a lot of important shadow area, the ISO setting might be higher than one would choose for a rich full scale subject, allowing either lower light levels or shorter scans. Some operations don't require full light; during focusing and other adjustments, scrims can be introduced between the lights and the subjects, or the lights dimmed if equipped with rheostats.[13] During interruptions, the piece can be covered or shaded.

Lenses can be used at wider apertures than customary when shooting film because scan backs feature electronic focusing aids which allow much more precise focus than the traditional method. Because high-resolution digital images can be viewed at extreme magnification on screen, imprecise focus or imperfect alignment of subject, lens, and camera are easily discovered, as are lens flaws. Once these are addressed,[14] the photographer can work comfortably at wider apertures rather than stopping down to gain depth of field.[15]

Light Sources and UV

Scan backs can be used with any continuous light, including daylight, tungsten, florescent. HMI[16] or even mixed sources as long as the light is homogenous across the subject. In the studio they work particularly well with special full-spectrum florescents and HMIs. Special tungsten lights from Tarsia Technical Industries are being used by MOMA and other institutions with good results. These have dichroic reflectors that pass much of the infrared out the back and away from the subject. This keeps direct heat away from the subject, but raises the ambient temperature, so effective air-conditioning is necessary. Conventional tungsten lights can be used with scan backs, the heat being the primary danger to delicate subjects. Ordinary tungsten sources produce more heat than visible light and their spectrum drops off at the blue to violet end. To achieve a neutral color balance, digital cameras have to boost the output of the blue sensors. They do this quite effectively, but this increased gain tends to increase noise in the blue channel, especially at the marginal light levels that might be used for light-sensitive subjects. However, some photographers prefer the sharper, more focused beam of tungsten lights for some kinds of work. Tungsten lamps in general have an UV component of about 70 miliWatt/lumens and

[12] MOMA was one of the pioneers in adopting this technology wholeheartedly, and their ambitious and well-planned digitization project has been a model for other institutions. See *Digitizing Photographic Collections: A Case Study at the Museum of Modern Art, NY*, Colet, Keller, and Landsberg, Spectra,Winter 1997.

[13] It's not advisable to turn florescents off and on, because they require time to warm up and stabilize.

[14] The Zig-Align, a simple and ingenious mirror device is a useful aid in aligning camera, lens and copy stage. Contact William Zigler P.O. Box 765, Menlo Park, CA 94026, 650 342 3704

[15] Close examination of these digital images forcefully illustrates the fact that depth of field is an illusion, based on the size of blob the eye will accept as a point (the circle of confusion.) As the lens aperture gets smaller, out-of-focus blobs get smaller, but there's still only one plane of precise focus.

[16] Hydragyrum Medium Arc-length Iodide lights produce daylight balanced illumination in an instrument resembling a tungsten fresnel attached by cable to a large ballast unit.

museums don't generally consider UV filtration necessary for them. Art Preservation Services of New York recommends.70 miliWatt/lumens as a threshold; higher levels requiring filtration.[17]

HMI's produce ample amounts of daylight-balance light and are favored by some commercial digital studios. They appear to be fairly rich sources of both infrared and ultraviolet[18], but at least one museum is using them for digital capture of paintings and sculpture, if not works on paper. According to Brad Flowers of the Dallas Museum of Art, a pair of their HMI's in soft boxes at 7 to 8 feet distance produce UV readings of 160 miliWatt/lumens. Bare at 4 feet, the UV level was 200 miliWatt/Lumens. HMI sources probably aren't appropriate for sensitive works on paper, but might be useful for large scale works of more durable materials, which are difficult to light brightly enough for digital capture.

New florescent designs have emerged to meet the needs of video and digital studios, and seem to be becoming the light of choice for most scan back photography. They're efficient, produce little heat, and emit a spectrum well suited to the sensitivity of CCDs. Because florescent tubes use ultraviolet internally to excite the phosphors that produce the visible light, they have been suspected as sources of damaging UV. Many museums require UV filters over any florescent gallery lighting. Most of the florescent studio lights on the market use Osram tubes. David Christensen of North Light Products has provided data for the Osram tubes used in his equipment, and the UV component appears to be no higher than that of tungsten lights. Measurements taken at the San Francisco Museum of Modern Art Conservation Lab seem to bear this out.

Recently, Thomas Palmer scanned a number of Ansel Adams photographs at the San Francisco Museum of Modern Art using a Dicomed scan back with a pair of 200-watt Balcar florescents with bare Osram tubes. Conservator Theresa Andrews took measurements at the copy stage, recording a luminance of 250 foot-candles (2688 lux) with an ultraviolet component of 50 miliWatt/lumens. Temperature was also monitored, and remained at 68 degrees Farenheit, ambient room temperature. Scans ranged from 3 minute to 9 1/2 minutes. The Balcar lights feature dimmers, variable down to 25% of full output and this feature was used to minimize exposure during focusing and other operations not requiring full light. Dimmed, the lights produced 15 miliWatt/lumens in the ultraviolet region.

Foot-candles	lux	UV	scan time (max)	lux/hours	equivalent exposure @ 50 lux (scan only)
250	2688	50 µW/lumens	9.5 minutes	425.6	7 hours 55 minutes

Last year, during another publishing project at SFMOMA, Robert Henessey digitized Carlton Watkins albumen prints using a Better Light scan back with two 120-watt florescent K-Lites. With 400 foot-candles (4300 lux) at the copy stage, UV levels were 100 milWatt/lumens. Scan times were only 3 to 3 1/2 minutes.

Foot-candles	lux	UV	scan time	lux/hours	equivalent exposure @ 50 lux (scan only)
400	4300	100 µW/lumens	3.5 minutes	251	4 hours 40 minutes

The Balcar UV readings were less than the tungsten average, the K-Lites a little higher, but not by a large amount. The florescent lights being used for digital photography don't seem to be strong sources of ultraviolet, the levels being in the vicinity of tungsten readings. With filtration, the amounts should be reducible to nearly zero. The lights made by North Light Products incorporate Plexiglas panels in front of the tubes, which the manufacturer will fit with UF3 ultraviolet reducing Plexiglas on request. Other makes could be fitted with UF3 shields, with care taken to allow space for ventilation between the tubes and the shield if the lights aren't fan-cooled like the North Light designs. The TTI tungsten lights at MOMA also have UV absorbing Plexiglas shields to eliminate the moderate amount of UV, and further reduce heat.[19]

Karen Colby assumes the absence of UV in her calculations. Timothy Vitale on the other hand didn't consider the ultraviolet component of cold cathode scanner lamps (assumed to be between 0.7% and 2.4% of total output

[17] The Elsec UV Monitor Type 2 instruction manual, Art Preservation Services, 539 East 81st Street, New York
[18] Arc sources like HMI and Xenon, have UV in their spectrum, some of which is blocked by the lens in front of the bulb.
[19] Colet, Keller, and Landsberg, *Digitizing Photographic Collections: A Case Study at the Museum of Modern Art, NY*, Spectra, Winter 1997

like other florescent sources) to be a significant factor.[20] Nor did Stefan Michalski in reference to flash exposure. Both affirm that sensitive materials are more affected by cumulative exposure to visible light than to the small amounts of UV under controlled light levels. The light exposures from scanners and amateur electronic flash are considerably lower than required by scanning cameras, however. If UV at these levels is a concern, it should be possible to eliminate it with filtration.

Museum Policy for Photography

Part of the rationale for digitizing fragile or sensitive objects is to provide access for study and scholarship without handling or exhibiting the original so often. It might be regrettable if many artifacts become available only in reproduction, but it would unquestionably extend the life of the original, and if fewer people see the original, the reproduction will be much more widely accessible.

Digital capture should reduce the number of times a piece would have to be re-photographed, as is common now to replace lost, damaged, or deteriorated transparencies. Although there's a lot of concern about the permanence of CD-R media, the data on them will probably have to be transferred to DVD or whatever becomes the next standard, long before the CDs themselves deteriorate.[21] Digital image archives will have to be maintained and migrated to each new storage medium or file format, but if this is done the images should suffer no loss and be useful for a long time.

Scanning cameras can record a greater range of values than can be displayed by any current means, recording brightness ranges of 10 or more stops. Color transparency film has a range of 5 or 6 stops and nothing else, print or video display, comes close to that. The top-end models exceed the resolving power of many lenses. Put another way, image quality is better than we can fully use at present and if deep-bit files of sufficient resolution are archived, they should provide adequate documentation for many years.[22]

Digital capture offers some attractive advantages, and a number of museums have already commenced digitization projects, regarding the light exposure involved to be justified by the benefits. If other studies support the conclusion that it involves the equivalent of a few days of exhibition time at low light levels, it should be easier to make informed decisions about digitizing collections and individual pieces, and to monitor total exposure more effectively.

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[20] Timothy Vitale, *Light Levels Used in Modern Flatbed Scanners*, page 12
[21] Concern over CD and other media longevity is pertinent in that the most dependable should be identified and adopted.
[22] Most scan backs operate at 14 bits per channel, recording 16384 levels of each primary color. Present print and display equipment uses only 8 bits per channel, for 256 levels. Bruce Fraser, among others, advocates archiving deep-bit files against future improvements in output technology.

Osram Dulux Compact Fluorescent Lamp Spectral Distribution

The relative spectral power distribution is determined mainly by the light color, whereas the different models and wattages have a negligible effect.

The spectral distributions shown below are therefore typical of all Osram Dulux lamps for the relevant light color.

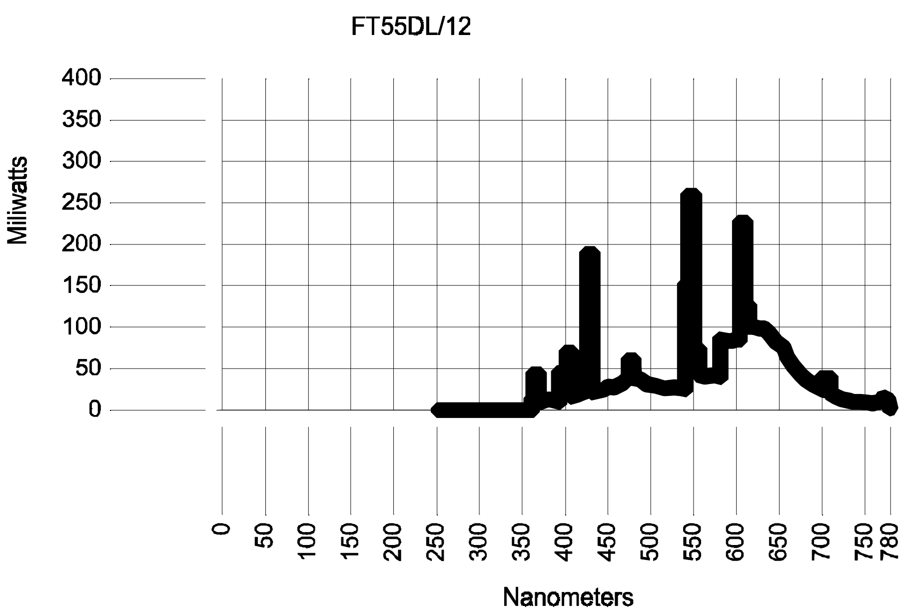
Y axis mW(m² x 5 nm x 1000 lx)   mW=miliwatt
X axis wavelength in nanometers

Notes on the charts:

The spectral irradiance distributions refer to an illuminance of 1000 lx. The advantage here is tat the absolute values of any illuminance can be found simply by dividing by 1000 lx:

$$\frac{\text{Illuminance E(measured) x (y axis value)}}{\text{1000lx}}$$

The spectral intensities are condensed into wavelength ranges of 5 nanometers. In other words irrespective of the actual distributions, the values given have been integrated over 5 nm. This corresponds to the standard applied to all calculations of consequential results (such as color and color rendering).



Osram Data courtesy of David Christensen, North Light Products

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Michael Collette, Larry Guyer, and Robin Meyers
Better Light, Inc.
1200 Industrial Road, Studio 17
San Carlos, CA 94070-4129
Phone 650 631 3680
Fax 650 631 2915
www.betterlight.com

David Christensen
North Light Products, Inc.
2487 Spring Street #2
Redwood City, CA 94063
Phone 415 366 5483
Fax 415 366 1676
www.northlightproducts.com

Better Light, North Light, and Balcar are distributed by Calumet Digital Solutions
http://www.calumetdigital.com/

Other sources and resources:

Garry Thompson, *The Museum Environment (*Butterworth-Heinemann 1994

Henry Wilhelm and Carol Brower, The Permanence and Care of Color Photographs, 1993, Preservation Publishing Company

Donald P. D'Amato and Rex C. Klopfenstein, March 1996, Requirements and Options for the Digitization of the Illustration Collections of the National Museum of Natural History at **http://www.nmnh.si.edu/cris/techrpts/imagopts/index.html**

Conservation Online website at **http://palimpsest.stanford.edu/**

Academic Imaging website at **http://www.academicimaging.com./**

Image Permanence Institute website: **http://www.rit.edu/~661www1/sub_pages/frameset2.html**