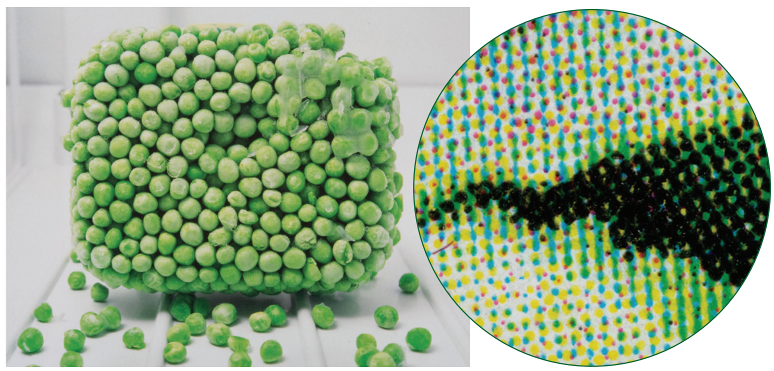
IPI's Guide to:

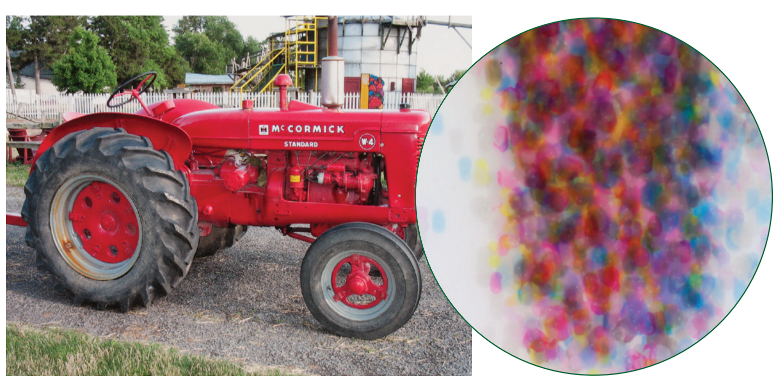
Preservation of Digitally-Printed Images

Electrophotography



Dye Sublimation

Inkjet



Introduction

The purpose of this guide is to provide basic information on the preservation of digitally-printed images in scholarly and cultural collections. While there are many printing technologies for output from computers, this guide focuses on the three most popular forms of image hardcopy: inkjet, dye sublimation, and electrophotography. It includes information to help understand these technologies, strategies to develop print identification skills, a schema for media naming, as well as recommendations for storage conditions, selecting enclosures, proper handling, and display. Although there are a wide variety of collection object types created using digital-printing techniques, including images, manuscripts, books, ephemera, etc., this document focuses solely on digitally printed images. The intended audience for this guide is collection care personnel in institutions; however, it may also be useful to photographers, artists, and the general public.

Should it be called digital?

Though digital technology was used in its creation, the printed object itself is not digital. It is recommended that the specific process (inkjet, dye sublimation, electrophotography,) be used instead to describe the materiality of the object.

Is it a print or a photo?

There has been some debate as to whether an inkjet print from a digital camera file should be called a photograph or a print. Since the inkjet paper is not light sensitive, inkjet printing is technically not photographic in nature. The preferred term is print.

Understanding the Technologies

Three technologies are used to print the majority of digital images: inkjet, dye sublimation, and electrophotography. None of these technologies was originally developed for computer output. Each process has an analog predecessor, which was later modified to print digital images.

Inkjet

The first printing device to utilize drops of ink emitted from a nozzle was developed by Lord Kelvin in 1867 to record telegraph transmissions. It was not until over a century later that inkjet printing devices were adapted for computers and became commercially available. In 1984, Hewlett Packard (HP) introduced the first desktop inkjet printers. From then, rapid developments in technology led to improvements in print quality, the inclusion of color, and the printing of images. Other major advances included color desktop inkjet in 1987, wide-format printing in 1993, full-color pigment inkjet in 2000, and inkjet digital presses in 2007.

All inkjet printers use drops of ink emitted from a nozzle to create colored dot patterns on paper (or other printing supports). There are two main types of inkjet printers – continuous and drop-on-demand. Continuous inkjet printers were the first to be used for high-end, fine-art inkjet images. The technology's original purpose was to create printer's proofs in commercial printing facilities. Continuous inkjet printers emit a constant stream of charged ink droplets. The drops can be electronically deflected into a recycling system or allowed to pass and hit the paper, which is attached to a metal cylinder rotating under the print head. A variety of papers can be used as long as they are flexible enough to fit around the printing drum. Currently continuous inkjet is used only in inkjet digital presses.

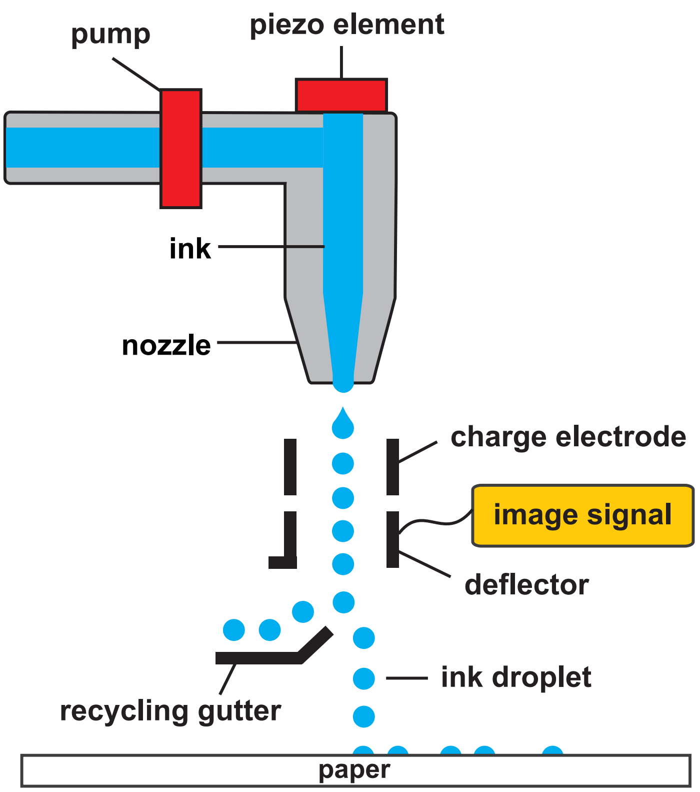
What's in a Name?

The term inkjet comes from the fact that ink is jetted from a nozzle to the paper. The ink must cross an air space before striking the paper. The print head never directly contacts the paper surface.

Drop-on-demand printers eject drops of ink only as required. There is no need for a deflection and recycling system. There are two different ways in which ink can be forced from the printing nozzle. The first, called thermal inkjet printing (also known as bubble jet printing), utilizes a heating element inside the print head to temporarily vaporize some of the ink and create a bubble. The formation of the bubble forces a drop of ink out of the nozzle. In the second type, a ceramic piezo electric tile flexes into the ink reservoir in the print head and physically forces a drop from the nozzle. All desktop inkjet printers and most wide format printers use drop-on-demand technology.

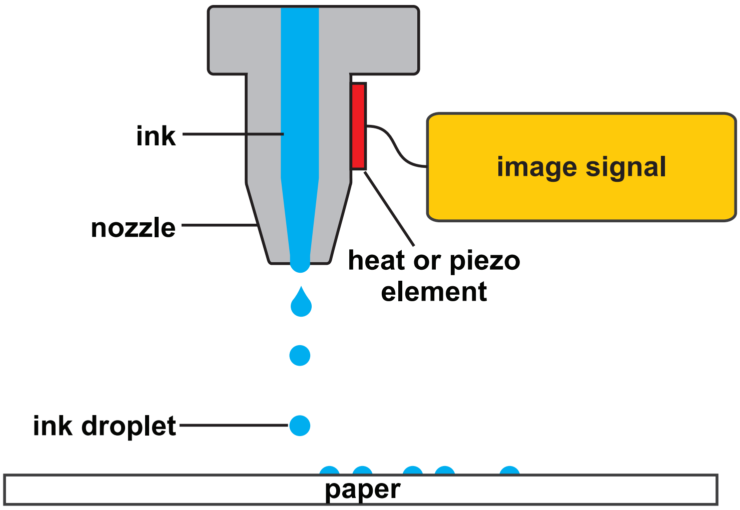
Inkjet inks can be water-based (aqueous), solvent-based, UV-curable, latex, or wax. These carriers of the colorant are the ink's vehicle. The majority of inkjet-printed objects in cultural collections were created using aqueous inks. The solvent, UV-curable, and latex inks are primarily used for industrial and commercial applications and only rarely for image or fine-art printing. Wax inks are used primarily for text, as opposed to images, as image quality is low compared to aqueous inkjet. The ink colorants may be either dye or pigment. Dyes are organic compounds that are soluble in the vehicle. Pigments are inorganic, organic, or a combination of both, but they are always insoluble in the ink liquid. Printers use either all dyes, all pigments, or a mixture of the two - where the colors are dyes and the black is pigment. In general, pigment colorants have tended to be more resistant to environmental deterioration (moisture, pollution, light), while dyes have been more durable during handling. Inkjet ink sets can be larger than those used in other printing methods.

Continuous Inkjet



Continuous inkjet printers emit a constant stream of charged ink drops. The stream of charged drops can be electronically deflected into a recycling system or allowed to pass and hit the paper (or the reverse where the deflected drops hit the paper and the undeflected drops enter the recycling system).

Drop-on-demand Inkjet



Drop-on-demand printers only eject drops of ink as required. There is no need for a deflection or recycling system.

While the most basic inkjet printers only use cyan, magenta, yellow, and black colorants, some high-end inkjet printers include inks of varying tone (such as greys, light cyan, and light magenta) as well as other hues (such as orange, red, green, blue, or violet) to improve the range of colors that can be produced.

A variety of papers are used to print inkjet images. Because plain paper absorbs ink in ways that diminish color and line quality, paper manufacturers have created special image receiver layers (IRL) for inkjet papers. These very thin layers are intended to keep the ink at the paper's surface and make the colors brighter and the lines sharper. These coatings were first applied to fine-art papers such as watercolor paper. The coatings were typically mineral particles in a starch or polymer binder. Ink was absorbed into spaces between the particles hence the name porous-coated paper. Early on, the mineral particles were too large to form a smooth glossy surface, so the papers were always matte or took on the texture of the underlying paper's surface.

As inkjet printing of images grew more popular, manufacturers began attempting to make papers that mimicked traditional photographic prints such as resin-coated (RC) chromogenic and fiber-based, silver-gelatin papers. The RC papers are coated on both sides with a thin polyethylene layer. The layer on the back is clear to show company logos printed on the paper, while the layer on the front is pigmented white to make the image appear very bright. There are two sub-types of inkjet RC papers – polymer-coated and porous-coated.

Polymer-coated inkjet RC paper swells and absorbs aqueous inks as they are ejected onto the paper by a printer. These papers are typically used only with dye inks because many pigment particles are too large to be absorbed into the coating. There are several advantages to these papers. One is that they can be manufactured to a higher gloss than the porous-coated papers, which is preferred by many photographers.

What is fine-art paper?

The term fine-art paper may seem too vague to some, especially those that have cared for works of art on paper made with other media such as watercolors or drawings. There are many supports made specifically for inkjet printing that rely on papers like these; however, a special image receiver layer has usually been added during manufacture to improve image quality. These papers are very different from the thin, inexpensive office papers used in inkjet printers to create documents. For the purpose of distinguishing these very different types of papers, it is recommended that "fine art" and "plain" paper be used respectively.

Also, because the ink is absorbed fully into the polymer layer, the prints are more resistant to abrasion during handling or fading caused by airborne pollutants. These papers have, however, become less popular because they can take several minutes to several hours to fully dry. Handling polymer-coated prints while they are still wet can lead to smudging of the inks. They are also sensitive to high humidity bleed.

As stated above, porous coatings were first used on fine-art papers. What differentiates porous-coated photo paper from earlier fine-art papers is the RC support to which the mineral coating has been applied, as well as the size of the particles used in the coating. In addition to having a plastic-laminated paper support, the particles used in the ink receiver layer are smaller and more tightly compacted than in most fine-art papers significantly increasing the glossiness of the paper's surface. Porous-coated photo papers can be used with both dye and pigment inkjet printers. One disadvantage is that while porous-coated photo papers are often advertised as glossy, they are not as glossy as polymer inkjet or traditional chromogenic glossy photographs. Also, because the pores remain open, even after drying, the colorants are not protected from the environment and are more susceptible to pollution-induced fading.

Many professional photographers and artists wanted inkjet papers that resembled the fiber-based, silver-gelatin papers they had been using for traditional photography. For this reason, manufacturers produced baryta inkjet papers. These papers may or may not actually use baryta, but what is common to all is the application of a smoothing layer between the paper surface and the porous ink receiver layer. The reverse side of the paper is not coated, or laminated with polyethylene, in order to maintain that fibrous paper "feel." In addition to papers, canvas has also been a popular support for inkjet, for both decorative art and photography. Canvas for inkjet printing always has a porous-coating.

What is coated paper?

The word coating is used in different ways across the paper, printing, and photographic industries, and there is no standard definition. Coating sometimes refers to sizing layers applied to the paper during manufacture to improve the paper's smoothness, opacity, density, or write-ability. In other cases, the term has been used to describe a special layer applied to the paper specifically to receive digital printing colorants. For example, a polyester layer is applied to RC paper to receive dyes during dye sub printing, or a swellable polymer layer applied to receive inkjet inks. These particular coatings or layers should be referred to as image receiver layers (IRL).

Dye Sublimation

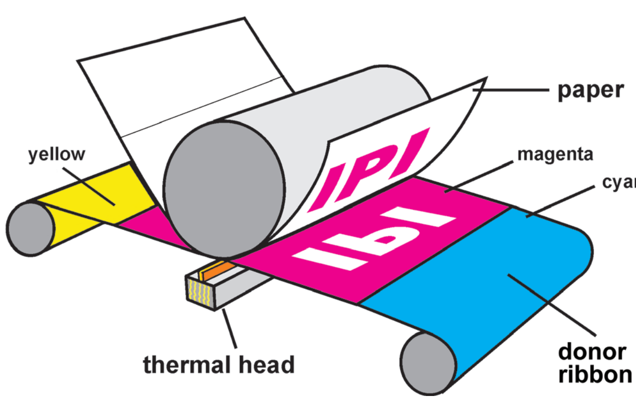
The concept of dye sublimation was first discovered by Noël de Plasse in 1957. As an engineer for the French textile company Lainière de Roubaix, he discovered that at high temperatures certain dyes would change from solids directly into gases and then, on cooling, revert to solid dyes. This discovery was not applied to imaging until 1982 when Nobutoshi Kihara, a Sony engineer, used it to print images from a still video camera. It took another four years before the technology became commercially available in 1986. This is the earliest year for these prints to appear in collections.

What's in a Name?

The term dye sublimation is often shortened to the nickname "dye sub." The technical name for the process, however, is dye diffusion thermal transfer. This too can be shortened to the acronym D2T2.

In these systems, the image-forming colorants are transferred to the print paper from a colored donor ribbon. A printer modulates heat energy to a dye coated donor ribbon to control the amount of yellow, magenta, and cyan colors that are transferred. This technology is most often used in snapshot-size printers and commercial photo kiosks, it has the advantage of producing images very rapidly compared to traditional photographic processing.

All dye sublimation printers use cyan, magenta, and yellow dyes to create an image. Papers are made from the same type of RC paper support used for chromogenic prints so that they look and feel like traditional photographs. The top layer that receives the heated dye is polyester, which readily receives the super-heated dyes. An important step in the evolution of this technology came in 1994 when protective overcoats began to be applied after printing of the colored dyes. Before this, dye sublimation images were unprotected and very susceptible to damage by light, pollution, humidity, heat, and water. Prints created before or about 1994 should be treated with a high degree of care, as they will be extremely sensitive to use and exhibition.



For dye sublimation, the thermal head heats the dyes on the donor ribbon causing them to diffuse into the paper's image receiver layer. After all the colors have been applied, a clear coating is applied over the dyes to protect them from moisture and airborne pollutants.

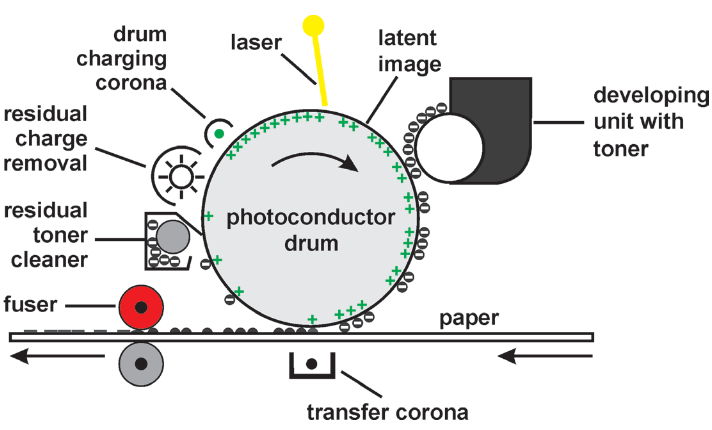
Electrophotography

Modern electrophotographic printers (i.e. laser printers) are digital but based on the same technology long used in analog photocopiers. Chester Carlson invented the electrophotographic process in 1938, and it was first commercialized in 1949. The conversion from analog to digital came in 1969 when Gary Starkweather of Xerox used a computer-driven laser to expose a photocopier's photo-conducting drum and thus create the first laser printer. IBM, however, was first to market laser printers with its 3800 laser printer in 1976. These devices were not desktop models, but room-sized machines that only large organizations, such as major corporations, would use. The first desktop version of the electrophotographic laser printer, the HP LaserJet, came out in 1984. The first desktop color electrophotographic laser printer became available in 1993.

What's in a Name?

Digital electrophotographic prints are often referred to as laser prints because a computer-controlled laser is sometimes used to create the image on the photo-conducting drum. The term laser print, however, can be a misnomer, as LEDs are occasionally used as the light source.

Also in 1993, both dry- and liquid-toner, full-color digital presses were introduced. These large-scale devices, used by commercial printing houses, can print single copies or thousands of copies with each imprint being unique. These new printers have two major advantages over traditional offset lithography. First is the ability to print on-demand. Digital presses do not need printing plates, therefore, the time required to make plates and tune their performance on the printer is eliminated. Secondly, unlike offset lithographic printers, which make a large number of copies of a single impression, the digital printers can make each page unique in what is known as variable-data printing. This feature has been utilized by the imaging industry to create photobooks, which are individualized collections of personal images printed and bound in a single-copy book format.



For digital electrophotographic prints, six steps must occur:

1. **Charging of the photo-conductor**
2. **Exposure**
3. **Development**
4. **Transfer**
5. **Fusing**
6. **Cleaning**

Digital electrophotographic printers use nearly the same technology as analog photocopiers with the main difference being how the photo-conducting drum is exposed. In the photocopier, a document was placed face down on a glass platen. Light was then reflected off white areas of the object to the drum causing selective exposure. In the laser printer, an electronic file containing the print data controls a laser which sweeps back and forth across the drum, turning on to expose certain areas and off to leave other areas unexposed. The unexposed areas can attract the colored toner, which can then be transferred and fused to paper. For an electrophotographic printer to create color images, four separate impressions (one each for cyan, magenta, yellow, and black toners) must be made.

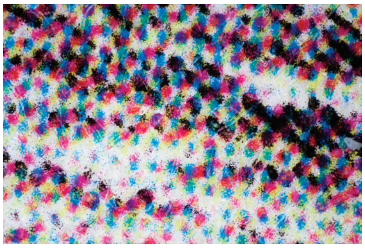
The image material used in electrophotographic systems is called toner. Dry toners are used in all current desktop and office printer/copier systems. Both dry- and liquid-toner systems are used in electrophotographic digital presses. Dry toners consist of pigments embedded inside polymer beads. A fusing process melts the polymer beads to the surface of the paper. Liquid-toners likewise use pigments in polymer beads; however, they are dispersed in a volatile oil that evaporates during the fusing process. For black-and-white printers the colorant is carbon black, which is typically very stable. Therefore, black-and-white electrophotographic prints made on high-quality alkaline papers should be very long-lasting. For color toners, a variety of pigment substances can be used. The stability of these can vary between manufacturers.

The papers used for electrophotography can be either uncoated or coated. The majority of desktop or office printer papers are uncoated and are usually referred to as plain paper, office paper, or copier paper. Coated papers are similar to plain papers with the exception that a heavy mineral layer has been applied to the surface during manufacture to increase the paper's density, opacity, and surface smoothness. This is the type of paper used in glossy magazines and often used in brochures, booklets, and posters. Coated papers are only occasionally used in desktop or office electrophotographic printing but are commonly used on digital presses.

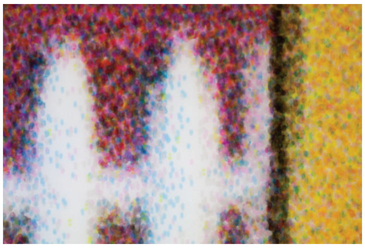
Identifying Digital Prints

The three most common types of digitally-printed images described in this guide can be distinguished from one another under magnification. Each has a particular look that acts as a "fingerprint" for that process. Below are photomicrographs of the most common variants of dye sublimation, electrophotographic, and inkjet prints. While these illustrate the most common features encountered, there are other variations within these three technologies and additional digital print type categories too numerous to include here.

Dye sublimation



Dry-toner electrophotography



Inkjet

The images above should not be used solely as a digital print identification tool but should form the basis of an appreciation of variations within digital printing.

The features illustrated in each of these photomicrographs is directly attributable to the technology used to apply the colorants, the types of colorants, and the visual and physical attributes of the supports. The dye sublimation image looks blurry because the dyes were diffused into the image receiver layer on the print paper. In addition, faint lines caused by the printer's heater array can be seen in areas of light to dark transition. The electrophotographic and inkjet prints look very different from dye sublimation because their images are formed by dots (a process known as half-toning). The dots that make up the electrophotographic image appear dusty while the inkjet dots are distinctly circular. Unfortunately, as stated above, among all printing and photographic processes there are many variations and subtypes that may appear similar or dissimilar to these three examples. In addition, many analog processes share attributes with digital prints often making distinguishing the analog from the digital difficult.

Developing the many skills necessary for digital print identification requires acquiring a basic knowledge of the materials and techniques used in these processes, taking hands-on classes with a skilled instructor, amassing references (sample sets, web-resources, publications, etc.), and significant amounts of practice. Identification is difficult due to the many subtle variations between digital prints, either within a category (i.e. inkjet on polymer-coated paper vs. inkjet on porous-coated paper) or between categories (i.e. liquid-toner electrophotography vs. offset lithography).

IPI's online digital print identification tool, which can be found at the DP3 Project website (www.dp3project.org), can be used to visualize different print types at different levels of magnification as well as under different lighting conditions. The DP3 Project website also provides information on the materiality of digital prints, descriptions of common deterioration and their causes, recommendations for preservation, and many other additional resources that can help institutions care for these materials.

To become truly proficient in digital print identification, practice is key. It is recommended that practice begin with standard sample sets of documented types. From there, practice can be expanded to collections of prints that are known to be digital, but whose specific types have not been firmly established. Lastly, practice with sets of prints that include both analog and digital will enable the practitioner to work within any collection that contains both types of objects to accurately identify.

Naming Conventions for Digital Prints

There are many terms used to describe objects in collections including authorship, title, and content. In addition, objects need to be described by their materiality. This is referred to as the object's media name. It is important that everyone accessing and using a collection, whether institutional staff or patrons, understand and use the same conventions for naming and describing collection objects. In the *Understanding the Technologies* section, the possible components of inkjet, dye sublimation, and electrophotographic prints were described. Combinations of these components range from very simple ink on plain paper to complex laminated structures. As such, media names for digital prints can be simplistic or complex depending on the need. For example, gallery labels will usually only need the name of the process, while conservation documentation will need the most specific description possible. With that in mind, the process term in the first column in the tables below will be the most succinct descriptor for that type of print and can be used as a gallery label. The qualifiers following the process in each table can be used to build a name that provides a more robust understanding of a particular digital print. While the following tables list the process and qualifiers from Process to Support, the preferred naming order will be colorant, process, image receiver layer (IRL), and support.

Brand Names

Brand names of printers, inks, or papers can be vital data to collect and save in cataloging systems, conservation documentation, and other important records; however, they should not be used as, or in, media names, descriptors, or on gallery labels. Because some companies manufacture printers and papers for multiple technologies, some confusion about an object's nature could occur. In addition, manufacturers sometimes change the chemical formula or physical structure of products without notice. Alternatively, the name of a product may be changed without changing its formula. Finally, brand names are not always known when an object is collected. For these reasons, it is better to use media names that truly describe the materiality of the object.

Inkjet

Each of the three qualifiers below are important for determining the long-term preservation needs of inkjet prints, and so each should be identified and recorded. The recommended media name structure is: colorant, process, IRL, and support.

PROCESS	COLORANT	IRL	SUPPORT
Inkjet	Dye Pigment Mixed	None Porous-coated Polymer-coated	Plain paper Fine art paper Baryta paper Resin-coated paper Canvas (Other)

Example: pigment inkjet on porous-coated baryta paper

Additionally, as stated in the description of inkjet technology, a variety of vehicles have been used in inkjet inks (such as water, solvents, waxes, and polymers) which can have a big impact on the durability and longevity of prints. Unfortunately, there are no known techniques to reliably differentiate the vehicle used for a particular print. The vast majority of prints in cultural and scholarly collections will have been created using aqueous inks. If the vehicle type is known to a high degree of confidence, it can be added as the first qualifier.

Example: latex pigment inkjet on porous-coated baryta paper.

If a specific qualifier for any print type cannot be determined, it may be better to use "unknown" as opposed to guessing or omitting it altogether. This highlights the importance of the attribute and the need to determine and record it when possible.

Example: aqueous inkjet on office paper (colorant type unknown).

Dye sublimation

The name of this process already contains the process (sublimation) and the colorant (dye). There is no vehicle, so that qualifier can be omitted. The IRL is always polyester, so that qualifier can also be omitted. The support is typically a resin-coated paper, though it can also be other materials such as metal or fabric. The recommended media name is: process and support.

PROCESS	SUPPORT
Dye sublimation	Resin-coated paper (Other)

Example: dye sublimation on resin-coated paper

Electrophotography

In electrophotography, pigment is always used as the colorant and there is never an IRL, so those two qualifiers can be omitted. Only the process, image material (dry or liquid toner), and support are required. The recommended media name is: toner type, process, and support.

PROCESS	IMAGE MATERIAL	SUPPORT
Electrophotography	Dry-toner Liquid-toner	Paper Plastic (Other)

Example: dry-toner electrophotography on paper

Gallery Labels

The media descriptor used on gallery labels should be the name of the process: inkjet, dye sublimation, or electrophotography. Non-standard names such as giclée, archival pigment, laser, etc. should not be used.

TITLE: *Tigers on Parade*
ARTIST: John Smith
DATE: August 25, 2018
MEDIA: Inkjet

Example gallery label

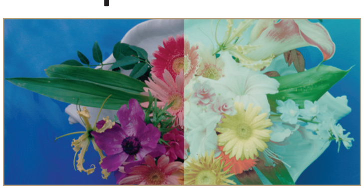
Preservation of Digitally-Printed Images

Storage

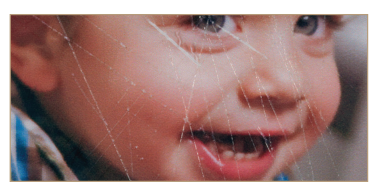
A variety of harmful forces affect collection objects in storage resulting in multiple forms of deterioration. For digital prints, the primary drivers of deterioration are heat, moisture, and air pollutants, though each print type will have its own unique sensitivities to each of these. Signs of deterioration include image fading, color shift, paper yellowing, ink bleed, and cracking or delamination of paper layers. The table below summarizes the types of damage caused by heat, humidity, and pollution. Control of temperature, humidity, and air quality in storage environments can significantly decrease the rate of change experienced by these materials. It is worth noting here that the sensitivities of digitally-printed materials to environmental factors are highly variable and product dependent. At times, the behaviors of materials within a category are greater than between categories. For example, two images printed on different manufacturers' inkjet printers using equivalent paper types may have radically different deterioration rates due to subtle variations in colorant and paper formulations. For this reason, all objects should be treated as individually as possible with condition assessments made on a periodic basis.

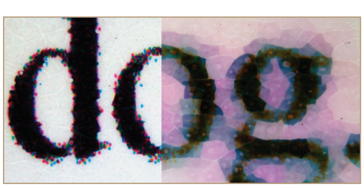
HEAT	HUMIDITY	POLLUTION
Yellowing Cracking Delamination	Bleed Blocking Ferrotyping Mold	Fading Yellowing Cracking Delamination Bleed

Examples of Deterioration

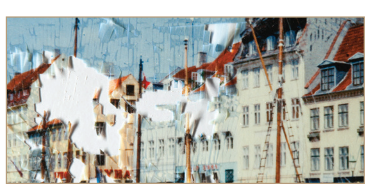

Fading

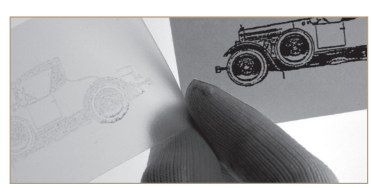

Yellowing


Abrasion/Scratch



Bleed


Cracking/Delamination


Vinyl Offset

Temperature and Humidity Recommendations

As with all collection materials, temperature and humidity control the natural aging rates of digitally-printed images. Extremes of either can cause significant damage that would not occur in proper environmental storage conditions. IPI data has shown that, in the absence of pollutant gases, digitally-printed image colorants are fairly robust at room temperature and moderate humidity. Unfortunately, some inkjet papers can be prone to significant yellowing and even deterioration of the ink receiver layers at room temperature. Low temperature storage can reduce these rates of decay and extend the usable life of these materials. **For this reason, IPI recommends cold storage for inkjet prints**. Dye sublimation and electrophotographic prints can be stored at room conditions.

The recommended storage conditions for each digital print process are shown in the following table. IPI recommendations from its Media Storage Quick Reference (MSQR) for traditional black-and-white and chromogenic photographs are also provided for comparison. The table allows users to thoughtfully merge multiple digitally-printed images and analog photograph types into four or fewer common storage conditions (Room, Cool, Cold, and Frozen). An RH range of 30%-55% is recommended for all storage categories.

STORAGE CONDITIONS	TEMP F	TEMP C	TRADITIONAL PHOTOGRAPHS		DIGITALLY-PRINTED IMAGES		
			B&W	COLOR	INKJET	DYE SUB	EP
ROOM	68° F	20° C	Good	No	No	Good	Good
COOL	54° F	12° C	Good	No	Fair	Very Good	Very Good
COLD	40° F	4° C	Very Good	Good	Good	Very Good	Very Good
FROZEN	< 32° F	< 0° C	Very Good	Very Good	Very Good	Very Good	Very Good

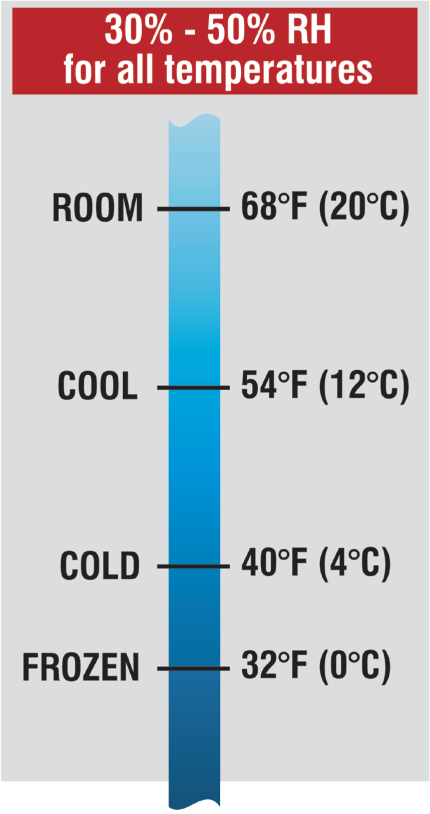
QUALITATIVE RATING SYSTEM	
No	Likely to cause significant damage
Fair	Does not meet recommendations but may be satisfactory for extended periods
Good	Meets minimum recommendations
Very Good	Exceeds minimum recommendations

Even though some print types are satisfactory at room temperature, the best conditions for all materials stored together will be cold or frozen. Note that “room conditions” does not imply human comfort levels or uncontrolled conditions but rather controlled temperatures between 65°-70° F and 30%-55% RH.

Note: The recommendations for inkjet provided here supersede those in the MSQR as that publication was created before the current digital print preservation research at IPI.

The Four Temperature Categories

It is useful to define the four categories (ROOM, COOL, COLD, and FROZEN) by single “anchor point” values. However, it should be remembered that, in reality, the effect of temperature on deterioration rates is always a continuum. The higher the temperature, the faster the decay, and vice versa. Most storage environments fall into one of these four categories. It’s very likely, however, that storage temperatures in a given space do not exactly match any of the four anchor points shown.



In this case, the following rules of thumb can help determine which environment best fits a given space:

- If the real-life average temperature is closer to one anchor-point temperature than another, simply apply the closest category. For example, if the storage temperature is 50°F (10°C), the environment would be considered COOL.
- If the average temperature is about equidistant from the temperatures on either side, consider both the cooler scenario and the warmer scenario.
- Any environment with an average temperature at or below 32°F (0°C) can be considered FROZEN.

Air Pollution

Pollution comes from a variety of sources including the air in a storage environment, offgassing from housing and framing products, adjacent collection materials, and from within an object itself. Of these, the greatest threats to digitally-printed images are air pollution and poor quality/reactive enclosures.

A variety of gases in the air can cause damage to digitally-printed images. Oxidizing agents such as ozone, even in low concentrations, can cause fading or yellowing of many print types as well as embrittlement of inkjet paper coatings. Acidic gases such as nitrogen dioxide can induce yellowing in all print types as well as bleed in some dye inkjet prints. For these reasons, exposure to air that has not been adequately filtered must be minimized. The low temperature storage conditions recommended above can help mitigate pollution-induced damage, but it is not equally effective for all gases. Ozone attack is only marginally slowed, while nitrogen dioxide induced deterioration is strongly impeded. Enclosures of low permeability, such as polyester sleeves, will be helpful in reducing the rate of air exposure.

Original image

Ozone-induced fading

Original image

Nitrogen dioxide induced yellowing

Humidity Extremes and Inkjet

High humidity should be avoided for all print types to prevent blocking, ferrotyping, and mold growth. However, inkjet dyes can also bleed severely when exposed to high humidity and result in noticeable image blurring and color fringing. These prints should be safe below 65% RH. However, time to bleed rapidly diminishes as RH increases. Prints exposed to over 80% RH can show noticeable bleed in less than twenty-four hours. In addition, very low RH levels should also be avoided as they can exacerbate brittleness of some inkjet print layers making handling more risky. Prints should always be handled in environments above 30% RH. This is especially true for prints that have been on display as light and pollution exposure can increase the brittleness of surface layers over time.

Enclosures

The primary purpose of storage enclosures is to provide physical protection for objects while not also posing a physical or chemical threats. Potential problems with enclosures include abrasion (resulting in scratches, scuffing, or smearing of colorants), yellowing of paper supports, and blocking or ferrotyping of print surfaces.

Enclosures can be fabricated from a single material such as a paper folder made from a sheet of card stock, or be more complex such as boxes made of stiff binder's boards covered with a decorative material on the outside and a white paper on the inside.

The approach suggested here is based on ISO standard 18902 *Imaging materials - Processed imaging materials - Albums, framing and storage materials*, as well as research on this subject performed at IPI. A majority of potential problems will be averted if, at the very least, this standard is utilized when procuring storage materials. Institutions should purchase this standard and collection care personnel should become familiar with its requirements. ISO 18902 can be applied directly to both dye sublimation and electrophotographic prints. It is worth noting here that vinyl plastic enclosures (PVC) should not be used with any imaging material but especially electrophotography as plasticizers in the sheet can soften toner and pull it away from the surface of a print.

It is more difficult to select safe enclosures for inkjet prints because of the diversity of the ink and paper formulations available and their individual chemical and physical responses to enclosure materials. The standard is not completely satisfactory for inkjet prints due to some unique issues associated with certain types, including adhesive-induced yellowing and bleed, as well as abrasion.

While ISO 18902 allows the use of pressure sensitive adhesives (PSA) directly on photos for mounting purposes, these adhesives should not be used directly on inkjet photographs. This applies to both dye and pigment inkjet. While most PSAs will be non-reactive, some can cause deep yellowing in a matter of months. The chemical mechanism of this problem is not yet known and no test method exists to predict the reaction. For these reasons, no PSA should be applied directly to inkjet prints even those that meet ISO 18902 or passes the Photographic Activity Test (PAT).

Key Points from ISO 18902

Enclosures should:

- **Be acid-free**
- **Be lignin-free**
- **Contain 2% alkaline reserve**
- **Pass the Photographic Activity Test (PAT)**
- **Not include chlorinated, plasticized, or cellulosic plastics**
- **Not include rubber adhesives**

Water-based adhesives (such as starch pastes used for hinging) should not be used on the versos of printed areas in dye inkjet prints because the moisture can migrate through the paper and induce bleed of the colorants. Water-based adhesives may be carefully applied to areas that are not directly behind colorants such as white borders. Additionally, adhesives that remain hygroscopic after drying can pull additional moisture into a print over time, further damaging dye-based images.

Even high-quality interleaving papers could cause colorant smear or polishing/burnishing of an image

The surface of pigment inkjet prints, or dye inkjet that used pigment for the black ink, can be extremely sensitive to abrasion. For this reason, only smooth plastic films, such as polyester sheeting, should be used in contact with print surfaces. The optimal approach is to not allow any material to contact a print's surface. This can be achieved by using window mats to keep objects separated while stacked. This may not be possible for extremely large prints, in which case smooth plastic interleaving and extreme care should be used.

Handling

The primary concerns when handling prints include abrasions to the surface (including scratching, scuffing, and smearing of colorants) and cracking (with or without flaking of print surface layers). The following tools and practices should be used to minimize the potential for damage.

Gloves

Gloves should always be used when handling photographic materials. There is no scientific evidence supporting a preference for nitrile or cotton gloves for digital prints; however, there are reasons to prefer nitrile to cotton for many collection objects including digitally-printed images. Nitrile gloves fit better, they don't tend to snag on edges, and they don't allow for contaminants to migrate through the glove over time.

Auxiliary Supports

Avoid touching the image areas in prints even with gloves. Hold prints at edges or underneath. The use of an auxiliary support such as a mat board to provide even support is preferred. This will prevent unintended flexing of the print, which can lead to surface cracking or crimping. In addition, inkjet prints that have been on display may have become imperceptibly brittle. This can be true even when other types of deterioration are not apparent such as color fading or paper yellowing. Flexing such a print may initiate cracking or even delamination of paper coatings.

Avoid Rolling or Stacking

Pigment inkjet prints, especially on soft, fine-art papers, can be extremely sensitive to abrasion and scratches. Prints should not be stacked directly on top of each other. Interleaving materials, such as plastic films, should be very smooth. Even high-quality interleaving papers can cause colorant smear or polishing/burnishing of an image. Prints should also not be rolled, as this stresses the image receiver layer and puts the print's inked surface in direct contact with the paper's verso, which can result in abrasion. Additionally, prints should always be allowed to fully dry post-printing before interleaving and/or stacking to prevent spotting, ferrotyping, or blocking.

Transport

There is no known research on the effects of transport on digital prints; however, it is likely that the primary concerns when transporting prints will be inertness of the packaging materials, potential for abrasions, air pollutants, and exposure to high humidity. It is preferred that no material be in directly contact with the surface of a print, especially for pigment inkjet prints. If a material must be in contact with a print's face then a smooth plastic such as polyester film should be used but secured in place so that it does not slide back and forth across the exposed colorant. Sealed packages can help prevent air pollution from impinging on the print causing fading, yellowing, or deterioration of image receiver layers. Seal packages can also help buffer against short-term increases in RH that can cause bleed in dye inkjet prints or blocking of polymer-coated inkjet papers. It is also important to note that many inkjet papers can absorb pollutants from not only the air but also poor quality packing materials. Damage may not appear until months or years later. Use packaging materials known to be safe as described in the section on enclosures above.

Display

The major concerns for digital prints on display are fading of the colorants, yellowing of the papers, and embrittlement of surface coatings. Display conditions should follow established practices for chromogenic prints such as the America Institute for Conservation of Historic and Artistic Works *Photographic Materials Conservation Catalog - Exhibition Guidelines for Photographic Materials*. The primary cause of damage will be ultra-violet radiation; however, energy in the visible spectrum can also contribute to deterioration. Objects should be framed with glazing to physically protect the surface as well as to protect against pollutant exposure. The glazing should block at least 97% of UV radiation. Framing materials should meet the same requirements for storage enclosures described above. As mentioned in the section on storage, environmental conditions can have a major impact on the deterioration rates of objects including those in exhibition areas. Extremes in humidity as well as high levels of pollutants must be avoided. Additionally, all prints on display should be periodically monitored to discover change before it becomes objectionable.

Digital Print Terminology

Abrasion
: *Surface damage, such as scuffing or colorant smear, caused by rubbing a broad surface across a print*

Aqueous ink
: *An ink that uses water as the vehicle*

Baryta paper
: *An inkjet paper manufactured to simulate fiber-based, silver-gelatin photographic paper*

Bleed
: *The migration of colorant across the surface of a print*

Bleed-through
The migration of colorant through the support to the reverse side

Blocking
The unintended bonding together of materials in direct contact

Canvas
A woven fabric, porous-coated inkjet support intended to mimic the textural and visual qualities of painting canvas

Cracking
Breaking or disruption of surface coatings often initiated by flexing a print

Chromogenic print
A traditional wet-processed color photographic print

Colorant
The substance (dye or pigment) that imparts color to an ink or toner

Color fringing
Bleed of a single colorant within an image containing multiple colorants such that the bled color appears strongly along image edges

Color shift
Print color change due to unequal fading rates of individual colorants and/or yellowing of the support

Continuous inkjet printer
Printer in which a steady stream of charged ink drops are ejected from a nozzle onto the support while unneeded drops are electrically deflected into a recycling channel

Delamination
Separation of structural layers in a print

Digital press
A large-scale inkjet or electrophotographic commercial printing press

Drop-on-demand inkjet printer
Printer in which the printhead nozzles release drops of ink only as needed to form the image

Dry toner
A toner made of pigments encapsulated in polymer beads that can be melted onto a support surface

Dye
An organic colorant soluble in the vehicle

Dye sublimation (also known as Dye Sub or D2T2)
A digital printing process that uses heat to diffuse dyes from a donor ribbon into an image receiver layer

Electrophotography (also known as EP)
: *An analog or digital printing process in which the image is formed by transferring charged toner to paper and then fusing it by heat (dry toner) or evaporation (liquid toner)*

Fading
: *Loss of colorant resulting in image lightening or color shift*

Ferrotyping
: *A change in a print's surface sheen due to direct contact with an adjacent surface under high humidity and/or pressure*

Fine-art paper
: *High-quality paper for printmaking, watercolor, or other artwork*

Flaking
: *Localized loss of surface coatings from a print*

Giclée
: *A term often used for marketing fine-art or fine-art reproduction inkjet prints*

Gloss
: *Reflectivity of the print's surface. Sometimes referred to as surface sheen*

Half tone
: *An image formed by a regular or irregular dot pattern in which the dots are all of equal density, and the illusion of tone is created by varying the size and/or distance between the dots*

Image receiver layer (IRL)
: *Coatings or laminates on the surface of digital printing papers to which the image material is applied*

Image transfer
: *Migration of image colorants to adjacent materials*

Inkjet
: *A digital printing process that produces an image by propelling droplets of ink from nozzles onto a paper surface*

International Organization for Standardization (ISO)
: *A worldwide developer of standards based in Geneva, Switzerland*

Iris print
: *A print created with an Iris Graphics continuous inkjet printer*

Latex ink
: *A viscous ink that coalesces and hardens under heat curing*

Liquid toner
: *A toner made up of pigments encapsulated in polymer beads carried in a solvent that evaporates during printing leaving the toner bonded to the support surface*

Mixed ink set
: *An ink set that includes a pigment black ink with dye cyan, magenta, and yellow inks*

Overcoat
: *A clear layer applied by the printer after the colorants to protect the image*

Photo kiosk
: *A self-serve station that permits customers to order prints or print images instantly from digital storage media or a built-in scanner*

Pigment
: *An organic or inorganic colorant insoluble in the ink vehicle*

Plain Paper
: *A typical office or copier paper*

Polyester
: *A clear plastic film used as the image receiver layer in dye sublimation prints. A clear or pigmented plastic film often used for enclosures.*

Polymer-coated paper (also known as swellable paper)
: *Inkjet printing paper in which the image receiver layer is a water-soluble polymer that swells and absorbs ink during printing*

Polyvinyl chloride (PVC)
: *A clear plastic film occasionally used in storage enclosures that can be harmful to prints*

Porous-coated paper
: *An inkjet printing paper coated with mineral particles in a polymer binder so that when ink is applied it will be absorbed into the pores between the particles*

RC paper (also known as resin-coated paper)
: *A paper laminated on both sides with a polyethylene film to impart rigidity and resistance against water absorption*

Scratch
: *Furrows or gouges in a print's surface, either superficial or severe, partially or wholly bisecting colorants and/or surface coatings*

Solvent ink
: *An ink that uses an organic solvent as opposed to water as the vehicle*

Sublimation
: *The conversion of a solid directly to a gas*

Surface sheen
: *Reflectivity of a print's surface, sometimes referred to as "gloss"*

Support
Any material on which an image material is applied during printing to create text, images, graphics, etc. - with or without a surface coating

Toner
The dry or liquid image material used in electrophotographic printers

Uncoated paper
A paper that has no special coating applied to the surface to receive colorants

UV-curable ink
An ink that uses a liquid polymer as the vehicle which hardens on exposure to ultra-violet energy

Vehicle
The liquid component of ink that carries the colorant to the paper surface during printing

Wax ink (also known as phase change ink or solid ink)
An ink that uses a wax as the vehicle, which when heated liquefies and can be ejected from inkjet printhead nozzles

Yellowing/staining
Discoloration of the white areas of a print

Recommended Resources

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About the Image Permanence Institute

The Image Permanence Institute (IPI) is an academic research center in the College of Art and Design at the Rochester Institute of Technology (RIT) dedicated to supporting the preservation of cultural heritage collections in libraries, archives, and museums around the world. IPI achieves this mission by maintaining an active preservation research program that informs and advances professional-level education and training activities, publications, consulting services, and the development of practical preservation resources and tools.

DP3 Project

Since 2007, the Image Permanence Institute (IPI) has been evaluating the stability of digitally-printed images as well as developing techniques for mitigating damage and extending their useful lives. Years of laboratory research have characterized the strengths and vulnerabilities of the most common digital printing materials and technologies. All of this work has been performed under the umbrella of The DP3 Project where DP3 stands for Digital Print Preservation Portal. Additional resources can be found at: www.dp3project.org.

DP3
digital print preservation portal

Image Permanence Institute
Rochester Institute of Technology
70 Lomb Memorial Drive
Rochester, NY 14623-5604
www.imagepermanenceinstitute.org
(585) 475-5199