Preservation of Ink Jet Hardcopies

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Introduction

1. Abstract

This research paper investigates the digital hardcopy process of ink jet printing. The focus is specifically on the physical nature of the print rather than on the printing technology behind it. As such, the investigation addresses primarily the concerns of the conservator, but also takes the interests of the archivist into consideration. The paper includes:

- a brief history of ink jet printing in the context of digital imaging and printing,
- a guide to ink jet printing technology as distinguished from other digital printing processes,
- image characteristics of ink jet prints,
- an illustrated identification guide,
- physical and chemical properties of ink jet materials,
- an investigation into internal and external deterioration factors and mechanisms for ink jet materials,
- thoughts on the preservation of ink jet prints
- a glossary and bibliography
- a collection of comparable prints to demonstrate various inkjet processes and materials. Each print is a hardcopy of the same file.

The outcome should include the acquisition of overall knowledge of digital printing technologies and detailed knowledge of the materials and media of ink jet hardcopies. Through the investigation of modern processes such as ink jet, it is hoped that permanence issues can be raised and deterioration problems minimized at an early stage.

2. Background

As digital imaging advances, so does digital printing technology. Industries are developing new output methods rapidly, and many photographic amateurs may switch to electronic cameras and desktop printers that can function without the additional use of a PC in the near future. A multitude of printing techniques for digital images already exists, the minority of which employ conventional color RC photographic paper. Artists in particular have been experimenting with new printing media, and their work will often end up in an art or photography collection or archive. There is as yet no compilation of information that covers the wide range of this new generation of prints, and thus the conservator has much trouble in finding identification guidelines and preservation recommendations in his/her work regarding the new print media. The permanence of conventional photographic prints depends almost as much on the correct processing of the prints as on the intrinsic problems of the materials used. In the case of the digital print, the processing is automated. Thus, the more important issues are those of the stability of the materials.

As technology continue to evolve, more and more prints of the digital generation will enter archives and the preservation problem will grow. As many technologies of this category are developed under the pressure of increasing competition, manufacturers are driven to utilize the cheapest methods and materials possible without decreasing image quality. Unfortunately, as has been apparent in the past, this approach often leaves no place for a high priority of material permanence. On the other hand, some manufacturers have realized that a stable print will sell better than an unstable one, and this is reflected in advertising campaigns. Sooner or later the conservators will have to care for images that are produced using these media. Due to the great variety of printing processes and their continuous variation, it can be very difficult for a conservator to find detailed information on the materials.
employed. With conservation of photographs as we know it today only having a history of about 30 years, we have the unique possibility of having a direct influence on permanence issues concerning these contemporary printing processes. This research project concentrates mainly on the ink jet family, not only because it is the most diverse among the digital printing technologies, but also because it is regarded to be the most promising for future developments of hardcopy output.

It is a necessary and common practice in conservation to prioritize objects in terms of their need for preservation. In view of the wide scope of ink jet applications today, this concept would appear to make sense in the areas of new technologies as well. Singling out one area regarded to be most worthwhile for preservation is surely the only way detailed investigation can be financed and carried out. However, it should not be forgotten that the quantity of noteworthy ink jet printing cannot be reduced to the artist eager to try out a new technique. Rather, ink jet is being used in organisations that still rely on paper archives and will continue to do so in the future, such as businesses, public institutions, advertising agencies, and many more. In view of this fact, the scope of ink jet hardcopy preservation widens considerably. Take for example any hospital, police, government, or business archive which aims to preserve documents. It is helpful to note how early advertising is now considered collectible. It will remain to be seen if today’s advertising prints will be deemed worthy of preservation measures in the future, but to rule this possibility out from the start would seem premature. Preservation needs to be one of the key factors in the production process of a print. If taken into consideration from the very beginning, the longevity of a print can be planned and become part of the print production process.1

A glance through magazines dedicated to printing and a look around trade fairs will show that image permanence is an important issue among manufacturers and that it plays a dominant role in their advertising. The conservator, however, should focus on those processes that he/she will have to deal with in his/her work. These would include prints that are being used by his/her clients and that have proven to have promising image stability qualities. A deviation from this would force him/her to study innumerable technologies as well as continuously keep up with the rampant progress in ink jet printing. In trying to give an overall yet detailed account of the printing technologies, chemistry of materials, and preservation issues, I have come to recognize the variety of ink jet products and their exponential effect of combinations as very broad. The further I progressed into this field, the further I understood the need for a selective concentration on a few promising processes, which might prove interesting for the conservator. At the same time I realized that, in order to make this selection with some authority, the market as a whole must be examined and sifted. Therefore, in this paper I have tried to introduce the conservator, collector, or curator to the big picture while going into detail on the issues and materials he/she might encounter in his/her handling of prints in the future. It must also be remembered that ink jet is everywhere: from business offices to advertising to governmental institutions to libraries to fine art. In other words, there are a great many individuals who might have to deal with ink jet prints in the future. It is hoped that this project, which should also serve as a basis for a materials database, might be of some help.

During the investigation, the question arose whether a new definition is needed for digital hardcopies that could compete with that of the “true photograph” and the “photomechanical print”. The contemporary definition of a “true photograph” that is widely accepted in the field of conservation is an object or a material that was at one point sensitive to light. The “photomechanical print”, also a contemporary term, is defined as a final object which was at no point in its history sensitive to light. As long as those interested in the processes can find a terminology that conveys their meaning well and is widely accepted, the definitions argument might be left aside. In this sense, the final object that is discussed in this paper is referred to as a hardcopy or print. The term hardcopy directly implies the object’s origin as being a digital file.

3. Goals

An investigation of a contemporary technology is difficult to accomplish. Since technology is continually advancing, the investigation quickly becomes outdated. In digital printing, the speed of technical development is so great that the investigation is doomed to be left behind unless it can constantly be updated. The idea, then, is to regard this paper as a basis for the development of a database on permanence issues of ink jet printing that would be built up little by little over time, parallel to technological advances. Interested individuals would be able to look up a wide variety of facts, experiment results, recommendations, etc., while simultaneously contributing to the database. The mass of information that cannot be gathered, evaluated, sorted, and made public by one person could be compiled by many individuals and offered to all. The ideal environment for such a database would be a site on the internet, as it is easy to update and widely accessible. A controlling entity would be necessary to keep track of postings and push for seriousness and reliability of information.
4. Target Group

This project, consisting of a guide, an information database, and preservation recommendations, is directed primarily towards conservators and restorers, and secondly archivists, collectors, and curators. This investigation can serve as a foundation for conservators in their own research and as an identification aid for digital prints in a collection. The fact that no hardcopies are present in a collection today should not exclude the possibility of their future presence in that collection, which is, in fact, very probable.

5. Evaluation of Effectiveness

The identification guide as well as the recommendations for preservation must be tested and evaluated by the end users for their correctness and feasibility. In addition, the information must be presented to the user in such a way that it is easily understandable. Four different types of potential users should test the product: a conservator, an archivist, a scientist, and a person from another field altogether.

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I. Ink Jet Printing

1. The Rise of Ink Jet

Ink Jet Basics

Considering the diversity of printing technologies, it is helpful to differentiate between analog and digital printing systems, even though some printing workflows incorporate both processes either side by side or consecutively. An analog process could be characterized as having a physical master, an actual matrix from which prints can be made repeatedly. A digital process, on the other hand, neither needs nor utilizes a physical master, but instead can repeatedly convert digital data directly into a printed product. Although contemporary analog workflows will almost always incorporate digital processing at some point, the final print will still be produced by a physical master. Finding and keeping these definitions is difficult in the ever changing technology of printing, but the above model simplifies the approach somewhat. According to this approach, ink jet printing can be classified as a purely digital process, in that digital data enters a printing device, which then produces a final print without having to first produce a master.2

Ink jet is a term that is understood today to group a variety of printing technologies that have one common factor: they all convert small quantities of ink from a reservoir into drops, and transport the drops through the air to the receptive medium. The simplicity and success of the concept has led to a great variety of applications and technical variations. But physical and technical limits have also slowed down the rapid climb of ink jet printing somewhat. It can combine important printing characteristics in a single technology, such as: color, high speed, high resolution, low cost, low noise, ability to print on various media.

1. Historical Development

Ink jet printing as a hardcopy output option is relatively recent, as is also the mass production of computers. Only in the late 1970’s did ink jet become interesting for industrial applications. In the late 1980’s ink jet was primarily used as a black-ink-only low cost alternative to a laser printer. But phenomena that apply to both continuous and drop-on-demand printing have been observed for over 200 years.3

1749: Nollet: Effects of static electricity on a drop stream
1833: Savart: Use of acoustic energy to form uniform drops
1859: Magnus: Experiments on electrostatic drop deflection
1865: Plateau: Relationship of jet diameter to drop size and frequency
1867: Thomson W. (Lord Kelvin): First practical work on continuous jet systems
1874: Patent for the Kelvin’s siphon recorder, which by 1876 was in use at the ends of telegraph cables. The siphon, which jetted a continuous stream of ink onto a moving web of paper, was moved horizontally back and forth by a drive signal.
1878/79: Strutt (Lord Raleigh): Theoretical treatment on the basic physics of continuous drop train formation in fluid jets due to inherent instabilities.
1929: Hansell: Electrostatic deflection investigations
c. 1932: RCA Communications: Ink jet recorder for radio facsimile: parallel to a printer for photographic film, an ink jet printer was employed, which had all of the functions of a modern continuous ink jet device: ink was forced through a nozzle, atomized, and projected onto a rotating drum with paper. An electromagnetically controlled deflecting vane could change the direction of the ink stream.
1938: Genschmer: Pulsed pressure drop ejector
c. 1950: increasing activity on application oriented technology and on the need to mass produce printer products
1964: R. G. Sweet: Patent on electrostatically deflected ink jets
1972: Zoltan: Patent on impulse (drop-on demand) ink jets
1984: Hewlett-Packard: 2225 ThinkJet, the first thermal ink jet printer on the market, in development since 19784 widely brought DOD for offices and letter printing
1996-97: introduction of 6 and 8 color ink sets to achieve near-photographic quality printing.

The market for ink jet is growing and with that growth there is a diversification of applications, inks and media. One analyst sees a growth factor of all digital media sales from 1995 to 2000 at 2%, but the growth of just ink jet media at 20% in those 2%. In 1994, the market was dominated to ca. 90% by thermal ink jet devices, of which about 50% were color devices. The number of color devices currently in use has increased dramatically. Technological trends deal mainly with enhancement of image quality as well as lightfastness. The diameter of the image forming dot is being reduced by utilizing smaller drops, and the continuous tone depiction is becoming more and more common. Once only reserved for large format printers, desktop devices are being sold today that render a photograph in photographic quality. Ink jet has definitely grown into a dominant position at the head of digital printing, and there is no reason that it should not continue growing at the expense of other printing technologies. Thus it is already and will in the future present a challenge to the collector, archivist, curator and conservator to confront ink jet prints.

2. Applications

Printing in black and white had been the norm for many years, but over the last 20 years a great increase in color output has been observed. Printing in color has become more and more important as computers have become faster, more versatile, and easier to use. In 1988 it was estimated that only 10% of all sold printers were color printers, but it was expected that the growth rate for these printers would exceed that of the printer market as a whole. The proliferation of color monitors and workstations as well as the advent of digital imaging and graphic design has increased the demand for color not only on the monitor but also in the output. Color has become almost an everyday aspect of printing, even in offices. The market for color hardcopy output is very applications-specific, in that some output technologies are better suited to some application areas than others.

The driving forces behind the incredible ink jet technology surge are advances in technology itself, newly found applications for ink jet printing, and meeting ever higher end-user standard demands. These include demands in image quality, printing speed, and print throughput. Of all digital printing processes, ink jet has turned out to be the most versatile. For this reason it is being used in a myriad of applica-

cations and is considered the most likely to completely dominate the color printing market of the future, which includes replacing large areas of printing that have until now been regarded as purely photographic.

Personal Computers

The advance of the personal computer (PC) into most areas of everyday life, including libraries, schools, and homes, has also brought hardcopy printing to everyone’s attention. As printers have decreased in size and expense, the small, at times portable, printer will fit on a desk, thus earning the name of desktop printer, accompanying the desktop computer. The desktop printer evolution from dot-matrix to black and white ink jet to color ink jet has allowed many individuals to afford to make their own color prints at home. This sector represents a market that is growing rapidly.

Office Environments

In the office environment, which is one of the largest users of desktop printers, most documents are still purely text oriented and black and white, but since color was discovered for office applications its use has increased dramatically. Certain text blocks or single words can be emphasized through color, and color graphics can be included to enhance the visual aspects of a document. Ink jet applications in the office and business environments include fax machines, office documents, presentation handouts, and overhead presentations utilizing ink jet printing on a transparent plastic substrate.

Industry

In the industry of goods manufacturing, product and package labeling is an important part of the production and marketing processes. Until recently, conventional printing processes such as offset and silk screen were mainly employed, but the flexibility and versatility that ink jet offers has become a major reason to switch to new printing methods. Silk screen and offset printing both require fixed matrices that must be produced and cannot be changed quickly. As spraying ink onto a substrate is completely digitally driven, the resulting print can be modified easily and even altered from one print to the next. Applications of ink jet in the industry include barcode printing and product labeling.

Printing houses use ink jet technology primarily for proofing documents before they are given the final authorization for going to press. A proof is a trial print which must resemble the final print as closely as possible in color, size, registration, and sharpness. It is cheaper and easier to produce than a trial run on an offset printer, for example, and it is used for communication with the client. The proof is signed by the client once it has been examined and corrected and counts as a guarantee between client and printer that the fi-

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7 e.g., the Epson PhotoEx and the Hewlett Packard PhotoSmart printers
8 Moore, p. 217
nal printed object will result as specified. Ink jet has been used extensively for proofing, as it can render relatively cheap, fast, and reliable results. As a proof has no long term value but rather must imitate a printing process as closely as possible, the main emphasis is on color gamut, simulation of ink-paper interactions, and substrate characteristics rather than on image permanence.

Advertising Agencies and Graphic Design

Ink jet printing has found a wide variety of applications within the graphic design and advertising sector. For the graphic designer, a desktop printer will quickly give a sense of a design when actually printed out as opposed to being seen on a monitor. Advertising offers the widest application opportunities for ink jet, as the prints do not require great lightfastness due to the temporary character of most advertising. Large format banners, which have become popular for temporarily decorating sides of buildings, are printed in long sheets which are then hung up next to each other to form a huge image. Posters for trade shows and retailers, containing typography as well as images, can easily be printed out to the appropriate size and mounted on board. Backlit and window ads require a medium with an adhesive backing. Floor advertising has recently become more fashionable. Prints that are to be displayed outside will often be laminated to protect them from environmental factors such as moisture and pollutants. Much of the longevity research of inks and substrates is being conducted for applications in advertising, as the prints are subjected to more exposure to light and UV radiation than in other areas.

Photographic Studios

The use of ink jet technology for outputting photographic images was recognized as a goal that was worth extensive research and investment into higher resolution and wider color gamut. This application has become apparent as one of the most important salability factors in the retail market, as can be seen when observing advertising and sales strategies. Ink jet manufacturers are out to imitate and even take over the conventional photographic market, as examples of the terminology used to sell new printers and media demonstrate: “Photo-Quality” (used by Agfa, Compaq, Hewlett Packard), “Photo-Realistic” (Alps), “Photographic Quality” (Alps), “Photo Paper” (Epson, Ilford), “Photobase” (Magellan), “Photosmart” (Hewlett Packard), “Photo Reproduction Quality” (Epson), etc. The definitions vary from manufacturer to manufacturer, whereby the terms are always used to distinguish between a more or less continuous tone image quality.

As photographic studios are venturing into digital imaging - some have already completely switched to using digital cameras and photographic quality printers - they will be offering their customers digital hardcopies as final images. After an initial investment, the benefits for these studios are turning out to be great, as they avoid all costs for film and chemical development. This has been the way for many catalog and some advertising photographers who mostly work under controlled studio environments, but also for portrait and wedding photographers. As their customers are accustomed to high quality photographic images, the photographers are dependent on high image quality in their digital output. For this reason, many have chosen to use either dye sublimation or high resolution ink jet printers. One photographer regards the contemporary problems with lightfastness of most ink jet inks as useful:

“From: John G ...
Reply-To: epson-inkjet@leben.com

... I started a thread in this group about print longevity, but I have to comment that there are times and reasons that I appreciate a short term product. In the "olden" days, there was "printing out paper," which was for impermanent proofs. If the client kept them too long they would fade away. Well, here's modern "printing out paper."  

If you WANT someone to buy a "permanent" print at a high price, let them see what it will look like in a lower cost version. Or just a little 4x6 proof, won’t be big enough to frame in a hallway, and won’t last that long anyway. As long as you’re up front with the customer, they have no complaints if it fades in a few weeks of sun exposure. If it lasts a couple of years... so be it. Maybe someday we’ll ALL have archival printers available at low cost. Till then, this is one option that’s available. ... 

John G ...”

Fine Art

Apart from the extensive use of ink jet technology for printing mass editions of reproductions of artwork for institutions such as hotels and hospitals, ink jet has been discovered as a new printing technology by print makers and the artists themselves. Artists have always had the freedom and the urge to explore new imaging processes, and digital printing has proved no exception. Computer art has become a category all for itself, and with the rise of technologies enabling a higher quality for image printing than was possible with dot matrix printers or plotters of the 70’s and 80’s, artists have become interested in the printing possibilities that modern digital printing offers them. Ink jet has played a major role in fine art printing, due mostly to the artists’ discovery of

9 The slightly simplified allusion here is to deliberately unfixed printed out images that were given to clients by some late 19th century photographic studios as proofs that would quickly darken significantly when exposed to light.

10 Epson - Inkjet mailing list, <epson-inkjet@leben.com>
large format continuous tone printers such as those manufactured by IRIS Graphics, Inc. in 1989.\footnote{11} IRIS mentions that the number of studios utilizing their printers for fine art printing has grown from 3 at the start of 1992 to 180-200 at the start of 1998.\footnote{12}

IRIS has become the primary hardcopy option for artists’ printing because of its high resolution, continuous tone, brilliant colors due to a wide selection of inks, a wide choice of media, and wide format. Many artists chose to print on a 100% rag paper with a rough surface, similar to a watercolor paper.\footnote{13} Originally designed to print short lasting proofs, the IRIS printer has been adopted by a number of fine art printing studios that have sprung up around the world and which offer edition printing of digital files in the tradition of art printing houses such as lithographers and etchers. Only recently have other large format printers edged their way into this specific IRIS market.\footnote{14} In the need to establish a category of its own in the realm of fine art printing, the term “Giclée” (French, meaning: to spray) has been adopted for fine art ink jet prints. Its use is disputed, however, as some believe it to be a mere attempt at increasing the marketability of the prints.\footnote{15} Two groups have been established that organize and educate digital fine art printing studios: the International Association of Fine Art Digital Printmakers (IAFADP) and Unique Editions.

Much effort is being put into increasing the longevity of fine art prints, as the art market demands knowledge of the permanence of an object. Not only is the purchase of an artwork often an investment, but the market value of an object is always partly determined by its condition. A faded print, be it photographic or digital, would thus sell for less than one with the original full color and contrast spectrum. This is an area that is much discussed by artists, ink and medium manufacturers, and printers.\footnote{16} Since many of the images of this category are of photographic nature or descent, the comparison in longevity to a photographic color print is always one of the first to be made. Some artists, however, do not regard the permanence of their ink jet prints to be of utmost importance, and scoff at the concerns of the art market and the conservators.

While there are those that cherish the tradition of limited editions from a printmaking studio and the feel of a print on heavyweight rough textured paper, others believe that the new technology should bring with it new rules and aesthetics. Charles Traub, of the School of Visual Arts in New York, NY, for example, emphasizes the importance of the digital file in its function as a “negative”, which can be used over and over to reprint an image.\footnote{17} The purpose of working digitally should accommodate the acceptance of unlimited editions and the idea of distribution as integral to photographic and digital technologies. Traub also stresses that not only is color in essence susceptible to change in light, but also that the avoidance of any technology by an artist due to its limitations would restrain that artist's creativity and disable his quest for stretching limits. He regards the use of watercolor paper for digital printing as a mimicry of “artistic” aesthetics similar to the Pictorialist imagery at the turn of the century. On the other hand, of three students questioned regarding their approach to their choice of media for ink jet prints, all preferred the feel and look of watercolor papers to the shiny or plastic substrates.

**Which areas will the conservator have to deal with?**

The applications for ink jet printing described above are categorized generically for the sake of simplicity, but show the width of the spectrum of uses for ink jet. The conservator will probably not be concerned with many of the applications, but the scope of objects in care of conservators today should be kept in mind when evaluating the necessity for ink and substrate permanence for each application. Due to the amount of ink jet printing in use today, priorities are being and will have to be made as to the selection of the most worthwhile objects. This is a common practice in conservation, and as we are observing the ink jet trends today it can be noted that the industry is the primary force in deciding which areas it considers worthy of extensive longevity research and which are negligible.

11 the year the presumably first fine art ink jet printing studio opened: Nash Editions, Manhattan Beach, CA
13 see Chapter II.4, Materials Analysis, Substrates, for details
14 e.g., Colorspan's DisplayMaker Large Format printer and ink set, Lasermaster Corp.'s Design Winder printer
15 interview with Stephen Johnson, photographer, on Oct. 31, 1998
16 see also Chapter III.1, Preservation Issues, Introduction
17 interview with Charles Traub, School of Visual Art, New York, NY, on Nov. 2, 1998
2. Technology, Principles, and Image Characteristics

The Non-Impact Printing Family

The process of applying ink to a substrate is traditionally a technology that utilizes contact between some part of the printing device and the paper. The use of physical impact gives this printing device category its generic name: impact printing. Most traditional printing processes such as offset, lithography, and flexography belong to the class of impact printers. In contrast, printers of the non-impact category utilize technology that allows them to apply ink to a substrate without physical impact, or pressure, between the printing device and the paper. Ink jet plays a major role in this category, as the ink is sprayed from a nozzle of the printing device, travels through the air, and hits the substrate.

1. The Ink Jet Family

In comparison to its non-impact siblings, the ink jet process is the most dependent on the characteristics of its substrate in determining image quality. On the other hand, it probably has the best color rendition and gamut. Ink jet can be classified into two broad categories: continuous and drop-on-demand. Both technologies are employed today and have different applications. There are also two categories of printhead structures: An array device employs a sequence of nozzles that are spread out along the full width of the media. The printhead is immobile, and the medium is pulled by beneath it. The second type employs a mobile printhead that is moved back and forth along the width of the medium while the latter is being pulled through the printing device. Array devices are typically continuous ink jet printers, whereas the mobile printheads can belong to either the drop-on-demand or the continuous category. Although there are further variations of both continuous ink jet and drop-on-demand, they will not be commented on in the context of this investigation.

Continuous

The principle of the continuous ink jet is precisely what the name implies: a steady stream of ink droplets formed at high rates is ejected from an orifice in the direction of the receptive medium (Figure 1.1). Those drops that are not meant to reach the substrate (the non-printing drops) are intercepted and recycled. The drops destined to form an image (the printing drops), on the other hand, are deflected in mid flight, thus passing by the interceptor and flying onwards to finally hit the substrate, forming an ink dot, which is the smallest image forming entity in an ink jet print. Some systems deflect those drops that are to be recycled and allow printing drops to pass. The rate of droplets issued from the nozzle is controlled by a vibrating piezoelectric crystal that can form hundreds of thousands of individual droplets each second. IRIS Graphics Inc. speaks of a rate of 1 million drops per second per nozzle each with a diameter of 20 microns. The droplets are charged electrostatically as they exit the nozzle, enabling the course of their flight to be influenced by the deflector, a further electromagnetic field that reacts to digital signals passed on from the image interpreting software known as the raster image processor (RIP). Thus the non-printing droplets can pass by the deflector unhindered, and are caught by a funnel that transports the ink through a filter to a reservoir for further use. Liquid ink is replenished as needed in exchangeable containers. As only a fraction of the discharged droplets are used for printing, most of the ink is constantly being filtered and recycled. This system tends to make continuous ink jet printing more expensive than drop-on-demand. In addition to this, an ink must be utilized that is dielectrically conductive, in order that it might be charged. This severely restricts the choice of inks usable in continuous ink jet.

Due to the overall design of continuous ink jet and the arrangement of charging and deflection plates as well as intercepting funnel, it has been difficult to get the nozzles close enough to the medium to be able to raise the print resolution much above 300 dpi. To compensate for this, some continuous ink jet printers, such as those manufactured by IRIS Graphics Inc., have the ability to direct varying numbers of ink droplets to one single location on the substrate, thus increasing the size and density of that dot in comparison to

19 see explanation in Drop-on-Demand section below
21 see explanation in I.2, Image Characteristics, below
others. In consequence, an effect much more like that of continuous tone, which is known from photographic printing, can be achieved. Restrictions on the inks that can be used for continuous printing are due to the necessity of the chargeability of the inks in order that it might be deflectable.

Continuous ink jet printers are used in many applications, some of which include low resolution monochrome package or mailing labeling, but also large format printing for advertising banners and posters, which generally do not need high resolution due to the typically large viewing distance. As mentioned above, optically very high resolution in large format can also be achieved with continuous ink jet, opening a realm of applications in fine art printing and art reproduction.

**Drop-on-Demand**

As the name of this category implies, drop-on-demand (also termed DOD and impulse jet) systems only generate an ink droplet if it is to be ejected onto the substrate to form a dot. Several printhead systems exist, which basically render similar results, as they vary primarily in their drop ejection process (Figures 1.2 and 1.3). One of the main drawbacks of DOD printers in comparison with continuous printers is their reliance on a drop forming cycle, that must be repeated every time a drop is to be ejected. The speed of this cycle is one of the determining factors of the speed of the printing process. Since printers have often been characterized by their DOD system, it is worth examining the differences.

**Thermal Printheads**

A resistor inside the printhead is heated, resulting in a phase change of the ink directly in contact with it. In this manner a vapor bubble is formed, which, as it grows, increases the pressure inside the printhead, thus forcing a droplet of ink through the orifice. As the heat is suddenly cut off, the bubble breaks, and the resulting pressure shockwave forces the droplet to break off from the orifice and fly towards the substrate. Due to the sudden decrease in pressure, the printhead refills with ink drawn in from the ink reservoir, and the cycle can begin again. This process, also termed bubblejet, was introduced by Canon in 1981 and by Hewlett-Packard in 1984 with the Thinkjet Printer. Thermal ink jet requires an ink that will react accordingly by vaporizing at a certain temperature, which can lead to the problem of kogation. This severely limits the ink formulations that can be employed. On the other hand, thermal printheads are less expensive to build than piezoelectric ones.

**Piezoelectric Printheads**

Of all of the above mentioned ink ejection techniques, the piezoelectric system is most versatile in the sense that it is the least restrictive in the type of ink that can be used with it, as it relies purely on a pressure shockwave as the ink drop expulsion force. This has made it popular and widespread, and inks that might have a higher color brilliance than those usable in continuous or thermal ink jet can be used in piezoelectric printheads. Piezo substances are crystalline materials that undergo mechanical stress when an electrical field is applied. Depending on the polarity of the applied voltage this can be either a minute contraction or expansion. The use of this distortion of the material in the confined chamber of a printhead allows for the reduction of the available space, which, similar to the bubblejet system, results in an increase in pressure and the ejection of a drop from the nozzle. Piezoelectric printheads function in cycles, the frequency of which also determines the printing speed. A typical piezo DOD drop volume is around 40-60 picoliters.

**Phase Change**

Although generally employed for liquid ink, as are all other ink jet processes, the piezo system can also be used for solid ink. Solid ink, consisting mainly of a transparent mixture of synthetic waxes, is used in phase change printers. It is purchased in the form of a pellet or stick, which is inserted into the printhead, where it is partly heated so as to form a liquid. This hot wax is then ejected by a piezoelectric printhead onto the medium. As the droplet hits the substrate, it freezes immediately, without allowing much of its substance to penetrate the surface of the paper. The result is an image that sits directly on the surface of the paper. Solidified droplets on the substrate tend to have a circular and spherical form, that actually acts as a miniature lens. A benefit of phase change printers is that they have the unique capability to print on nearly any media.

Hot melt ink jet can render fine lines and print very sharp edges, because there is no absorption or spreading of ink in the substrate. Further, phase change images show a high color saturation due to the fact that the ink is not influenced by the media it rests upon as strongly as liquid ink tends to be. One of the problems associated with phase change prints is that the image might be more susceptible to abrasion than a liquid ink print, but with a final step of cold pressure fusing the bond between the ink and the medium is greatly improved and the spherical droplet form is flattened out. The adverse effect the miniature lenses mentioned above can have on
transmitted light in the case of transparency film media, for example, is diminished by this step. In general, a continuous tone effect is not achieved with phase change printing, the application of which is mainly in representation of graphics and text. The ink is typically dyed. Although mainly utilized in moving printheads, the application of solid ink is being tested in array devices.

2. Image Characteristics

In order that ink jet prints might be understood not only in their aspects of materiality and stability, but also in terms of image quality, the characteristics of typical ink jet prints must be explored. Learning how to observe a print in detail and knowledge of some of the concepts behind the printing technology will also help in being able to identify an ink jet print, even if this merely consists of differentiating it from different printing processes. Some of the more important image characteristics are explained below.

Resolution

One of the major factors influencing the drive for better image quality is the smoothness of tonal variations or the invisibility of discrete dots in a printed image. Images are formed by an array of individual image forming entities, that, given a minimum viewing distance, merge to form a visual continuum of tones. The image quality of a photograph has long been the ultimate goal in ink jet printing. Various factors influence the image quality, among them are dot size, closeness of dots to each other, and placement of the drops relative to each other. A decrease in drop size does increase the illusion of continuous tone, however it must coincide with a closer placement of these drops to each other, as "holes" between the dots would otherwise become apparent. The number of nozzles in a row on a printhead in a defined width determine the number of drops that printer can eject simultaneously. In this context, spatial resolution is typically described in dots per inch (dpi). If a printer has 300 nozzles across one inch of its printhead, it could be said to have a print resolution of 300 dpi. In practice, however, driver software developed especially to control the ejecting of ink droplets can render a variety of resolutions from the same printhead (Figures 1.4 and 1.5).24

By printing multiple droplets of the same or of varying colors at one location, or by carefully calculating the effects of printing varying amounts of different colored dots over or next to each other, the apparent resolution, or that which the human eye records (or is "tricked" into seeing), can be increased. A high apparent resolution is the final goal, as it is what the print offers to the viewer. Next to the spatial resolution, the apparent tonal, or brightness, resolution is of importance. The brightness resolution determines the number of colors that can be discerned at one printed dot, and is also termed color depth. In a monochrome printer, the color depth

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24 e.g., the Epson PhotoEx can print in 360, 720, and 1440 dpi modes
of a single dot is either black or white, that of an area can vary in gray by alternating the percentage of black dots and non-printed substrate. In color printing, depending on the number of colors available, the color depth for one dot or one area can reach thousands of hues. Printers that utilize six inks, for example, strive to modulate colorant density instead of area coverage.\textsuperscript{25} The higher the tonal resolution, the more colors can be printed and the subtler the differences in color are perceivable. As mentioned in other parts of this paper, IRIS Graphics printers achieve apparent continuous tone by varying dot size as well as using the methods described here.

Print Uniformity

If the printhead is maladjusted, or parts of the nozzle array are clogged or otherwise disabled or obstructed, a typical visual phenomenon termed banding will appear on the print (Figure 1.6). As the printhead passes back and forth across the medium, regular lines of misplaced or missing droplets can appear, which are consistent over the whole printed area. Banding immediately disrupts the uniformity and impression of a continuous image, thus it must be avoided at all costs in the effort of achieving a photorealistic print.

Dot Size and Shape

Satellite drops, or small droplets interspaced between the actual printing drops, are typical by-products of continuous ink jet streams, which usually result in adding "noise" to a print, a deterioration of print quality (Figure 1.7). Some printers are designed to use satellite dots exclusively\textsuperscript{26} as image forming dots, because they are smaller, resulting in a higher resolution print at same nozzle size.

DOD printers tend to produce dots of uniform size, whereas continuous ink jet printers have the ability to print dots of variable size. IRIS Graphics Inc. speaks of varying dot density by printing from 1 to 31 droplets at one pixel, or smallest image forming dot (Figure 1.8). As a result, the dot diameter can range from about 25 to about 500 microns.\textsuperscript{27}

Dots ideally have sharp rounded edges, but due to bleeding, or feathering, on an uncoated paper substrate, the ink can be absorbed by paper fibers and filler substances causing irregular, uneven ragged edges, resulting in loss of image definition and acuity (Figures 1.9 and 1.10). The dot pattern can vary greatly, but all color ink jet printers overlap dots in order to produce the colors red, green, blue, and their variations.


\textsuperscript{27} Allred, Schwartz, p. 106
Ink colors

When a viewer looks at a color object or a print, the colors he sees are produced by varying proportions of red, green and blue light reflected from the object to his eye. In printing upon paper, the system has been developed by which three inks are applied to the white paper that can control the amount of red, green and blue light that is reflected. For this, the three primary subtractive colors yellow, magenta and cyan are used (Figure 1.11). Yellow ink has the ability to subtract blue light from the spectrum and reflect green and red, which together appear yellow. Similarly, magenta ink subtracts green light and reflects blue and red, and cyan ink subtracts yellow and reflects blue and green. If two of these subtractive colors are printed on top of each other, one of the primary additive colors will result. For example, if yellow and magenta are printed one over the other, both blue and green are subtracted, producing a reflected red. By varying the amount of ink deposited over the other, different shades of the reflected red can be achieved. If all three inks overlap, all of the additive colors are subtracted, and theoretically, no light is reflected, thus
the area appears black. In practice, that area only appears as a dark warm gray, as printing inks are never pure or strong enough to achieve a complete subtraction of light. As a result, a fourth, black, ink is used to add detail, contrast, and sharpness to the image. Printing inks must have a certain degree of transparency to achieve the full four-color process hue range.

Ink jet printing utilizes the same four-color printing technique to render a wide range of colors as found in conventional offset printing. Most color ink jet printers use four inks: cyan (C), magenta (M), yellow (Y), and black (K) (Figure 1.12). In order to achieve better skin tones in photographic images and more hues of reflected colors, or a wider color gamut, manufacturers have begun producing devices that will spray up to eight different colors onto the substrate. Ink sets of six colors include next to CMYK a lighter cyan, abbreviated with a lower case c, and a lighter magenta m (Figure 1.13), those of eight colors also include a y and a k. The additional use of these diluted inks enables a finer rendition of highlight details, a traditional weak point in ink jet, less graininess, and an apparent continuous tone otherwise only attributed to dye sublimation or photographic prints. Other manufacturers have developed specialty inks such as metallic reflecting to enhance the possibilities of the scope of printing. For details refer to the chapter on identification below.

Variables in printed color quality include differences in gamut, color saturation, also termed chroma, density of printed dots, brilliance of the colorant, and combination of medium and ink. The traditional method of color measurement of photographic processes has been to employ a densitometer which registers differences in red, green, blue, and overall density (RGB and D). In addition to this conventional approach, further methods for colorimetry are being tested. A standard for the measurement of the parameters of ink jet prints is currently in development. When measuring color with a spectrophotometer or a colorimeter, values can be interpreted with the CIE models, which enable differences in color to be expressed numerically, a benefit much appreciated in ink formulation and light stability testing. The diagram commonly used is the CIE Yxy, a two-dimensional representation of an actual three-dimensional model (Figure 1.14). It shows the color spectrum made up of single detectable impulses that can be registered by the average human eye. Using this diagram as a model, color producing devices can be compared in their capabilities. As can be seen in this comparison, ink jet printers produce a gamut that varies from that of offset printing, and both are only capable of producing a small part of the range of colors that the human eye is able to see. A wider gamut in ink jet prints is usually indicative of a lower lightfastness.

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29 e.g., Lasermaster Corp.’s Design Winder printer
I. Ink Jet Printing

3. Identification of Ink Jet Hardcopies

During the preparations for this short identification guide to ink jet prints questions arose regarding the value of an attempted overview of a printing process that is currently changing so rapidly. It was pointed out that contemporary ink jet prints were not permanent enough and thus not worth the effort of in-depth investigation. However, this might be just the time to be concerned with the developments in the field of ink jet, as it is regarded overall as the most promising for future imaging technologies. Understanding how difficult process identification is after only ca. 50 years of digital printing, it is imaginable how tricky it might get after another 50. Each year brings a multitude of new developments which make this identification guide almost immediately outdated. But the fact that there have been several attempts at organizing a process guide30 geared to differentiate between prints on account of visual examination will hopefully be of assistance to the future researcher investigating the history of hardcopy output or the conservator questioning the origin of the print in front of him. In the ideal case, the curator would find on the verso of each print that is being offered all of the information necessary for its identification and thus for its preservation. Henry Wilhelm has developed a program that has the goal of implementing this standard.31

One must question the necessary depth of the identification process. Is it enough to identify a print as the result of a digital process in contrast to that of an analog process, or must further distinctions be made? Does it really make a difference if a print was made on one medium or the other, or which inkset was employed? The answer should be simple: Any information that can contribute to the preservation of the object should be of importance. Determining the long term probable stability of a print necessitates its prior identification. If a print can be identified as having a substrate that is prone to deteriorate quickly, then a different archival environment and/or housing might be chosen by the conservator than if the object should be of importance. Determining the long term stability, which necessitates its identification.

When using this identification guide it should be remembered that it can by no means be regarded as a complete overview of ink jet processes, as each and every print will look different, even if printed on a similar printer and on a similar medium. It is important to keep in mind that due to driver software variables, print characteristics can vary drastically. The guide is intended to give an idea of the major differences between ink jet and other digital printing processes as well as show some of the variables among ink jet prints themselves. In practice, the concept of finding out the whole process details is unreal, rather, only certain factors might be determined. The visual identification process most likely will not result in detailed knowledge of a print such as the printer it was printed on, the ink set used, and the date it was made. It might, however, just be the observation that the image is indeed ink jet, and on a certain medium. This guide should sharpen the eye of the examiner for details that might turn out to be clues for the identification of a print, and encourage the user to expand the guide by supplementing his or her own experiences or print samples. The usefulness of a guide of this sort will have to be evaluated by its repetitive use, and it should be refined or expanded to adjust to the actual needs of a conservator. It is wise to remember that there is probably always a product on the market somewhere that contradicts any preconceived ideas or statements made here.

Important characteristics of ink jet prints are described in the paragraphs preceding this chapter (I.2. Image Characteristics), and are essential in understanding the variety and scope of the appearance of ink jet prints. Before embarking on the identification of a digital print, it should be remembered that, like all objects, ink jet hardcopies require that the examiner be conscious of the damage that can be inflicted on the object by mishandling. All magnified details presented below are from a sample file that was printed out on a variety of media and utilizing different printers and technologies.32

1. Methodology of Identification

In this identification guide, objects will be examined on a visual level only. Starting out with the naked eye, if necessary the examiner can proceed to using a loupe or a microscope. The restriction to a purely visual examination does not mean to devaluate other methods of material identification, such as spot testing with liquids or chemical analysis, but rather is understood to be the first step in a process that might or might not proceed to further steps. Leaving the realm of visual examination, material analysis methods become increasingly damaging to the object, so that if a print can be identified only by looking at it, not only can time, but also the


31 see Chapter III. 4. Preservation Concerns: “Approved Preservation Practices” Program

32 see Chapter IV. 7. Print Collection, for a description of the file and the collection of the original hardcopies
integrity of the object be saved. Among the materials that fall into the category of further chemical analysis are inks, laminates, and ink receptor coatings.

2. Primary Observations

It is recommended to begin the examination with a precise observation of the print in all of its details with the naked eye. By handling the print, with the necessary precaution, it is possible to get the “feel” of the object. By varying the incident angle of the light, different characteristics of the object can be revealed. Close examination of the image forming structure with the naked eye might already give away the process. Take note of the following variables:

Image Quality

The term image quality is difficult to define, as it is dependent on many factors, some of which can be of subjective nature. In this context, then, it refers to the degree of uniformity, sharpness, continuous tone and width of color gamut of a digital or analog print. If regarded as a visual signal that is transmitted from the medium surface to the eye, a printed image is subject to a scale of purity. The visual signal can be obstructed by noise such as that relating to the image forming dots, such as feathering, ragged dot edges, poor colors, large dots or spaces between dots, visually disturbing dot pattern, breaks in image uniformity, etc. As described in Chapter I.2. Image Characteristics, ink jet prints have a dot pattern that is in part distinct from other processes and in part very similar. Even among ink jet processes, the pattern varies greatly. With the naked eye, it might be difficult to discern the dot pattern. If this is the case, it is worth examining the print through a magnifying device. One give-away clue for ink jet prints is the visual effect of banding, that greatly disturbs the uniformity of the image (Figure 1.6). Banding might be obvious or very subtle, and it can sometimes take an experienced eye to make it out. Banding is not always present, however, especially in high quality prints.

Medium

Even if the exact composition of the medium is not immediately apparent, it is usually possible to determine the general class it might belong to: uncoated or coated paper, coated plastic, coated paper-plastic combination, or coated specialty medium. Comparison of the recto and verso of a print will often show that the former is whiter and brighter. This is indicative of the presence of optical brighteners and/or white pigments in an ink receptor coating on the image side of the print. Check the verso for a manufacturer logo or text, as a coated medium will sometimes be marked on the non-printing side (Figure 1.18). The absence of a logo or text does not indicate that the medium is not coated, however. The use of transmitted light will sometimes enable the discernment of an unevenness in opacity due to the irregular structure of paper fibers, indicating a paper support versus a pure plastic base (Figure 1.17). Here again, the reverse does not necessarily mean that there is no paper in the medium. The presence of cockling (Figure 1.15) or print-through (Figure 1.16) indicates the probable absence of an ink receptor coating or plastic layering.
Format

The format of a print can be misleading, as a larger print can easily be cut down to smaller size. As this change in format is not possible in reverse, the size of a print can exclude certain processes, for example, a poster sized print cannot have been made on a desktop printer. This distinction is important, as printers are most often only manufactured for one size format. A Hewlett-Packard PhotoSmart print cannot be larger than the standard US-letter, for example. It is important to remember that medium formats are continuously changing. While most are getting larger to accommodate the wider large format printers, some manufacturers are going the other way, in order to sell media that imitate conventional photographic format standards.

Color

Observe if the print is in color or in black and white. A print that appears to be black and white might be printed with four or more colors. Magnification can clarify any doubts. A monochrome print that consists of a color other than black is not necessarily a print from a color process, but could be the result of an electrostatic or electrophotographic process utilizing a colored toner. On the other hand, if a print shows a wide or any color gamut, it is definitely not from a monochrome process.

Surface

The surface of the print should be viewed in frontal and raking light. Surface characteristics range from dull matte to extremely glossy. Examine the uniformity of the surface on a glossy print, as the gloss is often influenced by the amount of ink deposited at a given location. Uneven gloss is a probable indicator for an ink jet print (Figure 1.19). An even gloss is not, however, necessarily an indicator for the print not being from an ink jet process. If the unprinted paper white is glossy, the medium is very likely to be of the coated type, although a matte surface can indicate either a coated or an uncoated media. Another indicator for the presence of a coating is a bright white, even surface which hides the paper fibers. If a matte print has relatively dull colors, the media is most likely uncoated. It should also be noted that a lamination on one or both sides of the print can modify the original surface of the medium.

Application

Determination of the original application of a print can be a clue to the process and materials used in producing it. An image used in outdoor advertising, for example, is likely to have integrated text, be printed with vivid colors at a relatively low resolution on a heavy and strong medium and have at least a one-sided lamination or coating of some sort. On the other hand, not every print that is on a banner medium, nor one that is laminated, must necessarily have been used for outdoor advertising. Fine art prints on watercolor type paper from about 1989 to 1997 can be identified as IRIS prints with a high degree of probability, a period during which the IRIS printer was the most commonly used system for this application.

Condition

The condition of a print can reveal much of its materiality and provenance. A heavily faded print has probably been on display, and an abraded surface would hint at much handling and use of the object. Ink smudging or running would indicate that the print has neither a protective coating nor laminate. A print that is matted and framed will have been valued by someone, with the possible consequence that it is printed on a material of higher quality.

Dating

A specific date associated with a print or written on some part of it can be a clue to the process employed. As the dating of processes and printers is a large task that would take much research, identification by date might be a very difficult and
tedious task. In this guide process dates have been left out due to the author’s current state of research in this area. If other identification clues are more helpful, it might be recommendable to neglect the dating of a print. The possibility of identification of prints on account of their dating is another reason for implementing an information database as proposed in the introduction and further below.

**Lamination**

Primarily, a lamination on one or both sides of a print will modify the surface characteristics. The effect of a laminate can range anywhere from a dull matte to a high gloss and can include a multitude of textures as well. Typical for laminated prints is a "plasticy" feel to the medium, that is best experienced by handling a variety of laminated samples. Identifying a sprayed-on coating is more difficult, however, as its application might have only slightly modified the surface characteristics of the original print, which are furthermore unknown to the examiner. The actual identification of the coating substance would have to be determined by analysis methods other than visual.

**3. Magnification**

Since an ink jet print can basically be on any substrate imaginable, have any color gamut, and show any surface characteristics, the best and most promising method of distinguishing it from other digital hardcopies, photographs, or any other kind of print, is to examine its image forming pattern under magnification.

**Pattern Variations**

As can be seen in the magnified detail shots in the section of individual characteristics below, the dot pattern can vary greatly not only between analog and digital processes, but also among the group of ink jet processes as well. This can confuse the examiner greatly, so it should be stressed that the observation of the dot pattern is usually only one of many clues that might lead to the positive identification of a print. Typically, the dots that make up a contone (short for "continuous tone") image will be small and close together, and they will often be printed over each other to form combination colors. The pattern may be regular or irregular, however. Large dots with large spaces between them indicate either a low resolution print for economical reasons, or a large format print designed to be looked at from a distance. As an increase in viewing distance increases the illusion of continuous tone, many banners and posters are printed at a low resolution to save ink and time. Fine art prints, on the other hand, are usually printed at an apparent high resolution to achieve the impression of a continuous tone even at a close viewing distance.
Ink Colors

Usually four distinctly colored dots can be made out in highlights: cyan, magenta, yellow, and black (CMYK). Highlights are the most probable areas to find these pure colors as they are least likely to be printed over one another to create further colors. In addition to the four basic colors, prints with near photographic image quality might employ diluted cyan and magenta inks, or even further diluted magenta, cyan, and black inks. Making out these dots in a print can be very difficult, and it helps to compare different prints to be able to determine the difference in dot color. As only certain printers employ more than four colors\textsuperscript{33}, the discovery of the lighter dots can be a clue to the provenance of the print. The presence of specialty inks will indicate other printers and ink sets.\textsuperscript{34}

Layers

Ink receptor coatings tend to be pigmented heavily with titanium dioxide in order to brighten up the whites and increase the contrast of the image. The coatings are opaque enough to completely obscure the paper fibers. If no fibers are visible under magnification, it is probable that there is a receptor coating. At the print edge it can further be determined if the print has a paper or plastic base. Single fibers protruding from the edge will indicate the presence of paper in the medium (Figures 1.20 and 1.21), whereas the complete absence of fibers points to a pure plastic substrate (Figure 1.22). If paper fibers are visible in all image areas, the medium most likely has no receptor coating. If the ink dots are sharp edged and fibers are visible, the paper has probably been specially sized to adapt it for ink jet printing. If, on the other hand, the dots show feathering, and the image colors are slightly dull, the substrate is likely to be uncoated bond paper.

The way the ink sits in or on the substrate also gives clues as to the presence of coatings. If the ink is deeply embedded in paper fibers, when magnified, it will appear strikingly different from ink dots on a coating. Solid ink from a phase change printer is distinct in that it features flat plates of shiny ink pressed onto but not into the fibrous surface of uncoated paper. The presence of a laminate can be detected by examining the print edge (Figure 1.23). Often corners will show more signs of wear than the straight edges, and thus the layered structure is more apparent.

\textsuperscript{33} Canon’s BJC-7000 printer uses seven inks: CMYK + low density cmy, Colorsnap’s DisplayMaker Large Format printer and ink set, the Ilford Archive Ink set, and Lasermaster Corp.’s Design Winder printer use eight inks: CMYK + light and medium cyan and magenta.

\textsuperscript{34} e.g., Alps metallic inks

4. Individual Characteristics

In this listing of the individual characteristics of different processes, the names of manufacturers and/or brands are left out for the most part, as the listings would be too long and still remain incomplete. It should be remembered that most media can be used in combination with most printers, so prints and processes mentioned and illustrated below are merely examples. In the following, some analog and non ink jet digital processes are described first, followed by ink jet processes.

For this identification guide, it was regarded as practical to use magnifications of a print area that included a human eye, with the goal of following the precedence and facilitating comparisons to the images of the processes described in the important book by James Reilly: Care and Identification of 19th Century Photographic Prints. Reilly’s choice of an eye incorporates a complete tonal scale from the shadows to highlights and consists of an image we can all relate to.

Figure 1.24. Chromogenic photographic print (RC paper), 30 x magn.

Chromogenic Photographic Print

1. Medium: color prints are printed on RC paper, Black and white prints can either be on fiber-based or on RC paper (Figure 1.24).
2. Surface: range of matte to glossy
3. Image Quality: true continuous tone, due to diffuse “clouds” of dyes integrated into the upper layers of the medium

Analog Halftone Process

Example A: Regular Halftone Screen (Figure 1.25)
1. Medium: There are almost no restrictions to either format or type of medium, as the ink employed in offset and flexographic printing is usually oil based and requires no specific coatings.
2. Surface: no restrictions, can range from matte to glossy and can be laminated
3. Image Quality: Depending on the resolution of the halftone
screen employed, measured in lines per inch (lpi), the image quality can be either very coarse or very fine. Typical for a halftone screen is a regular array of dots lined up in perpendicular directions. Each printed color has a specific screen angle. Variations in density are achieved by varying dot sizes but keeping a constant dot density. The regular halftone screen has a very typical appearance that is hard to mistake for other dot patterns. It can, however, be imitated by other processes such as ink jet. A monochrome halftone screen, typically black and white, is utilized by many desktop laser printers. Under magnification the dots of these electrophotographic processes can be distinguished from those of analog processes as sitting on the surface of the substrate.

4. Applications: very wide range

Example B: Frequency Modulated (FM) Screen (Figure 1.26)

3. Image Quality: In recent years a second screen pattern has been developed to complement the regular halftone. It consists of irregularly placed dots which, in a given print, are all the same size, and can easily be mistaken for the typical ink jet dot pattern. Tonal variations are obtained by changing the number rather than the size of the dots. Due to the irregularity and smaller size of FM dots, this printing technology is more capable of rendering fine details in continuous tone than is the regular halftone. In some printing applications, the regular halftone and the FM screen can be found in the same image area.

4. Applications: range generally restricted to high quality printing

Thermal Dye Sublimation Process
also classified as Dye Diffusion Thermal Transfer (D2T2) (Figure 1.27)

1. Medium: RC paper with many extra coatings to receive the dyes from a donor ribbon. The medium has the basic structure and feel of photographic RC paper. Eastman Kodak Co. medium has the words “Kodak ELECTRONIC IMAGING PAPER” in gray diagonal letters on the verso.

2. Surface: glossy. Eastman Kodak printers manufactured later than 1994 had the capability of applying a UV and fingerprint protection laminate over the image, the edge of which can often be made out when viewed in raking light at the edge of the image.

3. Image Quality: photographic quality, to the naked eye indistinguishable to photographic prints. Under magnification a soft grid is distinguishable.

4. Applications: proofing, photographic studios and retail stores
Electrophotographic Processes
1. Medium: uncoated bond paper of any color and varying thickness
2. Surface: Printed areas have a slightly glossy surface that differs from that of the substrate. A slight relief that is especially visible at borders between light and dark areas when viewed with raking light at an extremely small angle is an indicator for toner on the surface of the print, and is most prominent on color laser prints, where up to four layers of colored toner can be printed on top of each other.
3. Image Quality: varies greatly, depending on the printing process. Black and white laser printers usually employ a 45° angled regular dot screen similar to that of offset printing (Figure 1.28). Photocopiers finely distribute toner, as if "dusted" onto the paper irregularly (Figure 1.29). Color copiers and laser printers apply four layers of colored toner (CMYK) consecutively, each in a linear pattern but at a different angle (Figure 1.30). Common to all is the pigmented toner fused to the surface of the paper.
4. Applications: black and white office laser printers, some fax machines, photocopiers, color laser printers

Figure 1.28. HP LaserJet 5MP (bond paper, electrophotographic), 30 x magn.

Figure 1.29. Xerox photocopy (bond paper, electrophotographic), 30 x magn.

Figure 1.30. Canon CLC color laser printer (bond paper, electrophotographic), 30 x magn.
Phase Change Ink Jet Process
1. Medium: no restrictions in material, but usually uncoated media (Figure 1.31)
2. Surface: Printed areas, especially those with a heavy coating of ink, have a distinctly glossy surface that differs from that of the substrate. A distinct relief that is especially visible at borders between light and dark areas when viewed with raking light at an extremely small angle is an indicator for ink on the surface of the print (Figure 1.32). Although it might be damaging to the object, a finger can also be run over a printed and adjacent non-printed area. A slight relief might be discernible to the touch, which would indicate that the ink dots are hard spheres resting on the surface of the print. Although an electrophotographic print will also have a relief effect, it is not quite as prominent as that apparent on a phase change ink jet print. The surface is easily scratched or abraded.
3. Image Quality: brilliant, saturated colors, dots have sharp edges that do not bleed or feather. The image consists of round shiny dots that form a separate layer on top of the substrate.

Figure 1.31. Tektronix 350 (uncoated bond paper, phase change), 30 x magn.

Figure 1.32. Apparent relief on Tektronix 350 (phase change) in raking light, 30 x magn.
I. Ink Jet Printing

Ink Jet on Uncoated Bond Paper
1. Medium: uncoated bond paper, normally sized (Figure 1.33)
2. Surface: usually slightly glossy due to calendering, but can vary
3. Image Quality: paper fibers visible, ink dots have penetrated the fibers and might have bled along them (wicking), leading to an image that lacks sharpness and brilliance, colors usually dull
4. Applications: office environment, cheap and fast printing of text, not so much of images

Figure 1.33. Uncoated bond paper, 30 x magn.

Specially Sized Bond for Ink Jet
1. Medium: uncoated bond paper specially sized to accept and hold ink better than conventional bond (Figure 1.34)
2. Surface: usually slightly glossy due to calendering, but can vary
3. Image Quality: paper fibers visible, ink dots have penetrated the fibers to a lesser extent than on normally sized bond, and have feathered less
4. Applications: office environment, everyday printing

Figure 1.34. IBM Ink Jet Paper (uncoated but specially sized bond paper), 30 x magn.

High Quality Fine Art Ink Jet Paper (see also IRIS)
1. Medium: uncoated 100% rag paper similar or the same as watercolor paper, various degrees of weight, some types are specially sized for ink jet applications (Figure 1.35)
2. Surface: very matte and rough
3. Image Quality: the rough fibrous surface “swallows” the dots and diminishes the printing pattern to emphasize effect of continuous tone, single dots are hard to distinguish from each other.
4. Applications: fine art printing and reproduction of artwork on large format contone printers

Figure 1.35. IRIS: Somerset Velvet (100% cotton paper, specially sized, uncoated, continuous ink jet), 30 x magn.
**Coated Ink Jet Paper**

1. Medium: bond paper, RC paper, plastic film with white pigmented ink receptor coating (Figures 1.36 and 1.37)
2. Surface: matte to glossy
3. Image Quality: sharp edged, highly saturated dots rest on a pure white layer which obscures the paper fibers completely. The dot size depends on the printer and the print resolution.
4. Applications: very wide range, since this is the most utilized paper for images or text with images

![Figure 1.36. Epson Stylus PhotoEx, Photo Quality Glossy Paper (coated paper, piezo DOD ink jet), 30 x magn.](image)

![Figure 1.37. Epson Stylus PhotoEx, Photo Quality Matte Paper (coated paper, piezo DOD ink jet), 30 x magn.](image)

**Plastic Film for Ink Jet**

1. Medium: range from opaque to transparent. All films are coated in order to bind the liquid dye to an impermeable surface (Figure 1.38)
2. Surface: glossy
3. Image Quality: opaque plastics can have high, transparencies usually have low resolution. Ink dots are very round and have sharp, clear-cut edges
4. Applications: overhead presentations, graphic arts

![Figure 1.38. Coated transparent film (Piezo DOD Ink Jet), 30 x magn.](image)
Large Format Ink Jet
1. Medium: strong substrate of either banner cloth, canvas, plastic film and RC paper, with ink receptor coating
2. Surface: matte to glossy, often the print is laminated
3. Image Quality: usually low resolution, widely spaced big dots. Exception: IRIS and Colorspan’s Giclée Printmaker. Pigment based ink (Figure 1.39) usually shows a narrower color gamut than dye based ink (Figure 1.40), which provides for a more brilliant image.
4. Applications: large format indoor and outdoor advertising, fine art printing, reproduction of artwork

Specialty media
1. Medium: wide variety of coated materials, including canvas, fabric, banner stock fabric (Figure 1.41), transfer materials, floor advertising materials, fire retardant substrates
2. Surface: varies with the substrate
3. Image Quality: varies with the substrate, but has characteristics of prints on coated substrates
4. Applications: large format indoor and outdoor advertising, fine art printing, reproduction of artwork.
IRIS Continuous Ink Jet Process (see also Fine Art Ink Jet Paper)

1. Medium: varies greatly from matte (Figure 1.44) to glossy (Figures 1.42 and 1.43) coated media. For fine art applications uncoated 100% rag paper (Figure 1.46) similar to watercolor paper with various degrees of weight are used, some types of which are specially sized for ink jet applications.

2. Surface: varies greatly, fibers can be visible or hidden, depending on the medium

3. Image Quality: continuous tone at appropriate viewing distance, can show horizontal lines or noise in midtones termed “chatter” at magnification, on watercolor paper it is hard to make out dots at all (Figures 1.45 and 1.46). variable dot size, different dot patterns possible

4. Applications: proofing, fine art prints, reproductions of art

Figure 1.42. IRIS Photo Glossy (coated paper, continuous ink jet), 30 x magn.

Figure 1.43. IRIS Photo Glossy (coated paper, continuous ink jet), 40 x magn. Dots easily distinguishable

Figure 1.44. IRIS Matte (coated paper, continuous ink jet), 30 x magn.

Figure 1.45. IRIS: Somerset Velvet (100% cotton paper, specially sized, continuous ink jet), 40 x magn. Dots difficult to distinguish

Figure 1.46. Arches for IRIS (100% cotton paper, specially sized, continuous ink jet), 30 x magn.
Contone Photorealistic Desktop DOD Ink Jet Processes

Example A: Hewlett Packard PhotoSmart printer
(no illustration)
1. Medium: glossy RC paper (same stock and weight as photographic paper) with ink receptor coating is employed to imitate the look and feel of a traditional silver halide color RC print.
2. Surface: consistent high gloss in printed and non-printed areas, paper fibers hidden
3. Image Quality: near photographic quality, to the naked eye almost indistinguishable to photographic prints. Under magnification individual dots are blurred to make continuous tone, but their presence can still be sensed
4. Applications: desktop printing, home use

Example B: Epson PhotoEx
1. Medium: very wide variety. Contone media are either RC based or have a receptor coating (Figures 1.47 and 1.48). Epson Photo Paper (RC paper) has the words "EPSON Photo Paper" in gray diagonal letters on the verso. Uncoated paper can be used as well, but results in a less brilliant image (Figure 1.49).
2. Surface: matte to glossy, paper fibers hidden
3. Image Quality: at 1440 dpi print resolution near photographic quality, to the naked eye almost indistinguishable to photographic prints (Figure 1.47). Under magnification individual dots are sharp, but render near continuous tone
4. Applications: desktop printing, graphic arts, advertising agencies

Figure 1.47. Example B: Epson Stylus PhotoEx, Photo Glossy Paper, 1440 dpi (coated paper, piezo DOD ink jet), 30 x magn.
Figure 1.48. Example B: Epson Stylus PhotoEx, Photo Glossy Paper, 720 dpi (coated paper, piezo DOD ink jet), 30 x magn.
Figure 1.49. Example B: Epson Stylus PhotoEx, Ink Jet Paper, 720 dpi (uncoated paper, piezo DOD ink jet), 30 x magn.
1. Ink and Medium Interaction

The most important factor in determining image quality in an ink jet print is neither the technology and design of the printer and printhead, nor the software driving the printing, but rather the compatibility of ink and medium, which is governed by their interaction with each other. As print quality is the major selling factor for new products, it has determined most technological developments in ink jet technologies. The print characteristics that are governed by ink - medium interaction include optical density, or the deepness/darkness of the ink in the final print, color, resolution, dot size, dot shape, edge definition, and edge sharpness (Figure 2.1). The key moment in printing is the point at which the ink hits the substrate and the physical and chemical actions that take place as a result. The important factors in viewing the final print as an object to be preserved deal not only with the physical and chemical characteristics of the materials used, but are also influenced by the locality of the ink in relationship to the substrate: the immediate ink environment. Thus the interaction of ink and substrate govern the preservability of a print and deserve to be investigated in more detail. In this chapter various process models are introduced, the material details of which are exemplified in the following chapters. The complexity of interactions demonstrate how important the matching of ink and substrate can be.

Ink - substrate interaction can be viewed as a step-by-step process governed by the substances involved and the relationship of their characteristics to each other:

Step 1: liquid ink droplet hits substrate surface.
Step 2: liquid ink interacts with surface in various ways, depending on surface and ink characteristics.
Step 3: liquid ink may pass through surface and interact with substrate bulk.
Step 4: liquid ink dries or solidifies, leaving solid image forming substances on and/or in medium.

1. Printing on Uncoated Paper

The first and most obvious papers that were used in ink jet printing were typically sized, sometimes calendered bond papers as used in a multitude of applications. Their surface finish is of importance to their acceptance of a liquid such as an ink. Uncoated bond papers show under magnification an irregular network of paper fibers that can vary in composition and compactness. A calendered surface will have a higher gloss than a non-calendered paper, which appears to have a dull surface. Latter is due to the high relief of surface paper fibers that scatter reflected light in more directions than do the pressed down, more even fibers of a glossy paper. Next to surface roughness, fiber size and paper porosity play a role in ink acceptance. The top surface of bond paper may also contain additives, fillers, and sizing, which all have an influence on the resulting pH of the immediate ink environment.

The print density, or optical density (OD), of an ink jet hardcopy is the visually perceivable and densitometrically measurable absorption of light on the surface of a dry hardcopy due to the presence of a colorant. The optical density of an image is determined in part by the quantity and strength of the colorant in an ink, but also by the location of the colorant in the medium structure. Ideally, the colorant particles of the ink droplet should stay near the surface or on top of the paper to achieve high print density. If the colorants are soaked into the base of the paper, their print density will be weakened by the opacity of the fibers and the fillers that are between them and the surface of the medium. Absorbed dyes cannot contribute to optical density as well as “bunched-up” dyes. The bleeding of the ink due to capillary action along the paper fibers, termed wicking, deposits colorants in a greater area around the initial impact point, thus minimizing the quantity of dye in the originally intended area. Wicking, or feathering, leads to a decrease in print density at that point, as well as loss in dot edge definition. Also, larger dots are formed on

35 see Chapter II.3, Receptor Coatings, for details
the paper which results in a loss of print resolution.\textsuperscript{36} The surface tension and viscosity properties of an ink have a great influence on the resulting degree of wicking. Finally, the paper surface has light scattering properties, as described above, that can decrease the print density.

One solution is to keep the ink at the surface of the media for an appropriate period of time, in order that the solvent part of the vehicle might evaporate and only a small volume of the ink sink into the paper at a slow rate. The result is a smaller dot spread on the medium surface and a lesser penetration of colorant into the medium. This method may work in monochrome (black) printing, but when printing with more than one color, the ink must be absorbed into the medium relatively fast, as the different colored inks might otherwise have the opportunity to mix on the surface and thus blur. Adjacent different colored areas could bleed into one another to form undesired hues and cause poor print uniformity in solid image areas. It is difficult to achieve good monochrome letter printing and at the same time good color printing capabilities in one medium - ink combination.\textsuperscript{37}

The drying time of an ink jet print is of great importance. Printed dots that are still wet can smear either when being transported by the printer rollers or when the substrate is removed from the printer. The ink of a wet print can transfer to other prints if it comes in contact with them. The availability of the print for use must be as immediate as possible, as no user would want to have to wait for a long time until the print is completely dry and thus not as susceptible to smearing. In order to overcome the optical density problems described above associated with printing on paper, a higher quantity of ink must be sprayed onto the paper in order to achieve a satisfactorily dense ink dot. The amount of liquid that the substrate must absorb may be sufficient to lead to cockling of the paper, and the image can often be seen through the verso of the print as it has penetrated far into the base of the substrate, also termed print-through, or show-through (Figure 2.2).\textsuperscript{38}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig2_1.png}
\caption{Reflection and transmission characteristics of various media:
\begin{itemize}
\item a) Wicking of ink leads to decrease in resolution and print density, penetration causes print-through, irregular refraction causes matte surface appearance.
\item b) Wicking less severe, irregular refraction causes matte surface appearance.
\item c) Irregular paper surface appears matte, solid ink reflects full strength and has even surface, thus appearing glossy.
\item d) Irregular coating surface appears matte, solid ink reflects full strength.
\item e) Even coating surface appears glossy, solid ink reflects full strength.
\item f) Transparent film lets light through, ink intercepts at full strength.
\end{itemize}
}
\end{figure}

\textsuperscript{36} see Chapter I.2, Image Characteristics

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig2_2.png}
\caption{Figure 2.2. Cockling, left, and print-through, right}
\end{figure}
A colorant that shows substantivity, or a certain chemical affinity to cellulose, will bind to the fibers and in this manner separate from its ink vehicle, which is free to be absorbed into the paper base of the substrate. Similarly, a mordant can be integrated into the ink that will enable a binding mechanism between the colorant and the fibers.\(^{39}\) The importance of a bond between the colorant and the substrate for image permanence must be emphasized, as a good bond enhances waterfastness, lightfastness, as well as mechanical stability of a print. Ink absorbing properties of a substrate, on the other hand, determine image quality.

### 2. Printing on Coated Substrates

The problems that have been described in the use of plain paper as a substrate for ink jet led to the development of special coatings that are applied to papers and other materials. As these coatings can be manufactured to work specifically for individual needs, manufactureres have tried to tackle all of the problems posed above in the coating formulations. Similar to the introduction of a binder in the important step in photography from salted paper prints to albumenized paper, the most important effect of an ink receptor coating is its ability to hold the image forming particles above the surface of the substrate, and in doing so to enhance the optical density, brightness and contrast of the final image by overcoming the light scattering factors mentioned earlier. Ideally, the colorant of the ink must be separated from its vehicle as soon as the ink hits the coating. A mordant integrated into the coating can bind the colorant, and the moisture is quickly absorbed by substances such as silica, which are integrated into the coating. Due to the absence of fibers in the uppermost layer of the medium, no capillary action wicking takes place and as a result the image appears sharper.

### 2. Inks

In general, inks for ink jet printing must fulfill a long list of requirements, many of which contradict each other, resulting in trade-offs and compromises in many areas. An ink can generally be defined as the mixture of a colorant in a vehicle. A colorant is a substance with the ability to absorb a certain range of wavelengths from visible light, thus reflecting only the non-absorbed wavelengths, which is perceived by the eye as color. A vehicle is a fluid or solid substance, depending on its physical state and on its desired function, that serves to either dissolve or disperse another substance or a range of substances and render them usable in a certain environment.

Colorants are either dyes or pigments, and the vehicles used in ink jet inks can be classified into the two generic groups of water-based and solvent-based vehicles.

#### 1. Pigments and Dyes

The general distinction between the two colorant types is that pigments are finely divided, or powdered, solid particulates which are dispersed in a vehicle to form ink, while dyes are molecular and dissolved in a vehicle.

**Pigments**

Traditionally, inorganic pigments such as natural minerals were used by painters and printers, as they were known for a higher light stability than that of dyes. Inorganic pigments are comparatively few in number, have only fair color strength, and are usually dull and dirty in hue, such as iron oxides (commonly known as rust), chalk, clay, or lamp black (soot), but can also have vivid colors, such as malachite or lapis lazuli. In the mid-19th century the discovery of synthetic dyes and pigments that were of organic nature opened up the development of a vast array of colorants that could be chemically modified according to specific needs and color specifications. The synthetic dyes have intense colors and can be converted to new pigments, many of which as a result have a high color intensity from the originating dyes and at the same time the high lightfastness pertaining to a pigment. Organic pigments also result in a more transparent ink than do inorganic pigments, which tend to have a higher degree of opacity. Due to all of these advantages, the majority of pigments used in ink jet ink today are organic.

Organic pigments are produced by chemically “stacking” organic dyes to form larger particles. Formerly water soluble dyes are stacked like wet glass plates on top of each other, forming a crystal-like structure that precipitates out of the aqueous solution. By varying the choice and order of the dye molecules to be stacked through chemical manipulation, color control can be exerted over the resulting pigment. The extent of the stacking and with it the final size of the pigment crystal can be kept under control with the use of stopping molecules that fix onto the top and bottom of the stack. A typical pigment particle that has a diameter of 1 micron contains about 1 million dyestuff molecules, while soluble dyes provide only one.\(^{40}\) Some organic pigments will incorporate a metallic salt in their structure.

In order to be of practical use for an ink formulation, a pigment must be ground down or built up to individual particles of appropriate size, which for ink jet ranges from

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\(^{39}\) one such substance, cycloextrin, is explained in more detail in Chapter II.2, Inks

have a surface area of 30-130 m²/g. These factors demonstrate that the use of pigments poses in ink jet inks, the majority of inks used today employ dyes. Dyes have the advantages of being more transparent, having a higher tintorial strength, or more brilliant colors, and rendering the printhead useless. On the other hand, a larger pigment particle is more lightfast and resilient to chemical degradation than a smaller one. If a pigment is too finely ground, it could increase the viscosity of the ink, which would have an effect on the flow characteristics. Pigments also tend to stack or clump, which might be visualized with the idea of wet glass plates sticking together. Pigment crystals can aggregate to larger particles, then agglomerate to even larger clumps. This process is also called flocculation, and can lead to the total breakdown of an ink. Generally, the smaller the pigment particles, the better color, gloss, and transparency the ink will have, but also the worse the lightfastness, and the more surface area each particle will have, which again can lead to more aggregation. Due to the relationship between volume and surface area, the smaller the pigment particle is, the higher its relative surface area will be. Thus a pigment particle with the diameter of 0.02-0.4 microns could have a surface area of 30-130 m²/g. These factors demonstrate the complexity of acquiring the optimal pigment particle size in a given vehicle. As the lightfastness of a colorant increases with its state of aggregation, compounds that promote this reaction can be incorporated into an ink receptor coating to lend the print more light stability, since once the ink has arrived at the paper and deposited the colorant, an increase in particle size would be beneficial.

Since a pigment is insoluble in common solvents or water, the even dispersion of a pigment in its vehicle must be controllable. This is achieved by various processes of altering the wettability characteristics, or the ease by which a pigment can be wet by an ink vehicle, of the pigment particles. To avoid clumping, pigments can be first dispersed in solvents that will ease their later introduction to the aqueous ink, a process referred to as flushing. Another method is encapsulation, in which a pigment is encased in a resin which can have a variety of functions. Surfactants, or soaps, can also facilitate the dispersion of pigments in either water or solvents. The texture of a pigment is another factor that is important in ink jet inks. The harder a pigment particle is, the more abrasive it will be in the printhead and the more it might endanger the integrity of the fragile nozzle opening. Organic pigments are generally softer than inorganic ones.

Dyes

Dyes have played a large role in the history of the use of colorants. Natural dyes, such as henna, chlorophyll (plant green), and sepia (extracted from cuttlefish, this dye was used in an ink for many 19th century drawings), were extracted from plants and some animals and used extensively. Due to their ability to dissolve in water and solvents and their more brilliant hues, they were ideal for the coloring of cloth materials. The fact that dyes are highly sensitive to light makes historic textiles very susceptible to fading. In the 1850’s, synthetic dyes such as aniline were developed, and further research led to the production of organic pigments from dyes through chemical engineering, as described above.

Due mainly to restrictions in size of colorant particles that the use of pigments poses in ink jet inks, the majority of inks used today employ dyes. Dyes have the advantages of being more transparent, having a higher tintorial strength, or more brilliant colors, and rendering a purer rendition of color due to the fact that their units are single molecules, which are smaller than the particles of pigments, which have surface characteristics that refract light, thus adding a certain amount of noise to the reflected light which in turn leads to a duller or matter surface. The great disadvantage of using dyes in ink jet applications is their poor lightfastness. As a result, ink manufacturers have to accept compromises and trade-offs in their search for the ideal ink.

As ink jet inks are generally either water or solvent based, the dyes utilized can be classified according to their solubility characteristics as either direct dyes (acid or base), which are soluble in water, solvent dyes, which are soluble in solvents, or dispersed dyes, which must be dispersed in a suitable solvent. Solvent dyes display better waterfastness on a print than direct dyes due to their solubility.

Color Formation

Understanding the basic physical and chemical mechanisms of color formation in organic substances greatly helps to examine the reactions that lead to loss of color, or fading. For this reason a brief introduction to the origins of color will be given here.

The physical production of color requires three things: a source of light, an object that it illuminates, be it reflective or transmittive, and a detector such as the eye and brain or a technical instrument. Light is a form of energy that can be described as an ondulating ray which has a certain distance between the peak of each wave, termed frequency (Figure 2.3). This wavelength is measured in the unit nanometer (nm). Visible light has a range from about 380 to 760 nm. Shorter

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41 Eastman Kodak Co. introduced a new, fully pigmented ink claimed to be milled 10 times finer than other pigmented inks (Oct. 1998).

42 Scott Williams, Foto-Wear, Inc.

43 The following description of color formation is necessarily simplified to fit in the scope of this paper. The concepts introduced stem from the current theories of color chemistry.
II. Materials Analysis

Wavelengths result in ultraviolet radiation, and those that are longer than 770 nm are infrared radiation. Different wavelengths are interpreted by the brain as different colors: light of 450-500 nm is perceived as blue, while that of 550-600 nm is yellow, for example. White light ideally consists of the sum or full range of visible wavelengths, called the spectrum (Figure 2.4).

Colored light is perceived when a certain range of wavelengths is removed from the full spectrum that makes up white light, thus unbalancing it and leaving over the remainder, which is received by the detector. The determining entity that has influence on the range of wavelengths of light that travel from the object to the detector must then be the particles that make up that object, which are, in the case of ink jet printing, the spots of ink on the print. Seen on a molecular level, the dry ink spots are made up of a mass of dye or pigment molecules, that each have the ability to selectively absorb only a certain range of wavelengths while reflecting the rest, which thus make up the color of that dye or pigment. If yellow light is absorbed, for example, the colorant will appear blue; absorbance of blue and red would render the colorant green. The color purity of a dye is determined by the degree of selectivity it shows in absorption. The narrower the principal absorption range is, the purer its reflected color. The degree of absorption with its maximum (called the maximum extinction coefficient) determines the tinctorial strength of a given colorant (Figure 2.5).

Absorbing light amounts to absorbing a certain amount of energy, called excitation energy, which will excite electrons in the molecule, thereby advancing the molecule from its energy-poor ground state to one of its possible energy-rich excited states. This step consists of a shift of electron density, or a delocalization of electrons in the molecular structure. During excitation, electrons from one area may shift their positions to a different area in the molecule, thus unbalancing the stable ground state and forming the excited state. Following this, the molecule will return to its energy-poor ground state again. The cycling from ground state to excited state...
and back produces the color we perceive. The more energy absorbed by the molecule, the greater the energy difference between the ground state and the excited state. The range of energy difference a molecule can handle determines which light wavelengths it can absorb, and, in consequence, which it will reflect.

The energy difference range of an organic molecule is determined mostly by its state of conjugation relative to its size and the chromophores and auxochromes that are a part of the molecule. Chromophores are chains of atoms that have single and double bonds between them and are a part of the structural skeleton of the molecule. Auxochromes are functional groups that can be either organic or salt-forming and are attached to the molecule to modify and/or intensify the color of that substance. Both terms are somewhat antiquated, and it is more exact to refer to the chromophores as electron withdrawing and auxochromes as electron donating groups, both which have an influence on the electron density shifts along the molecular structure. The complete molecule without the auxochrome is usually termed chromogen (Figure 2.6).

### Examples of Chromophoric Groups

- `-C=O` carbonyl
- `-C=S` thiocarbonyl
- `-C=C-` ene
- `-N=N-` azo
- `-N=O` nitroso
- `-N03` nitro
- `-C=NH` imino

### Examples of Auxochrome Groups

- `-OH` hydroxyl
- `-NH2` primary amino
- `-NH-` secondary amino
- `-S03H` sulfonic acid
- `-COOH` carboxylic acid
- `-Cl` chloro
- `-Br` bromo

The presence of conjugated structures is necessary for color production. A long conjugation length means high electron mobility. A break in conjugation somewhere along the molecular structure necessarily limits the electron mobility. This concept can be understood by the metaphor of an object tied to a short or long string which is made to swing back and forth. The shorter the string, or conjugation length, the higher the oscillation frequency. A long string, on the other hand, will cause a low oscillation frequency. Thus the more mobile electrons present (the longer the conjugation length), the lower the energy requirement of that molecule for excitation by light. A molecule can only absorb that range of energy that will correspond to its excitation potential, in this case the low frequency of low energy red light (ca. 680-760 nm), which makes it reflect blue light.

Increased conjugation length leads to a bathochromic shift (deepening of shade, or a shift to absorbed red and thus reflected blue). In contrast, a molecule with a short conjugation length only allows for a lesser delocalization of electron density. This corresponds to the shorter wavelength and higher energy content of bluish light (ca. 400-450 nm). The absorption of bluish light appears as reflected red and is termed a hypsochromic shift.

In conclusion: a colorant is capable of selectively absorbing a specific range of wavelengths of light when illuminated. The wavelength of maximum absorption indicates the hue of that colorant, which consists of the wavelengths not absorbed by the molecules but instead reflected to the viewer's eye. The color of a dye or pigment is described by the maximum extinction coefficient, which indicates which wavelength range is absorbed most by a given colorant in a given vehicle. A highly pure colorant will have an extinction coefficient that is sharply cut off at each side. Any absorption outside of the principal absorption band will cause a reduction in the purity of the colorant. It should also be noted that the choice of ink vehicle will influence the chromatic behavior of the colorant.

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II. Materials Analysis

Organic colorant classes

Of the four kinds of pigments available (inorganic, metal salt pigments, lakes, and organic), synthetically produced organic pigments are the ones most commonly used in ink jet inks. Most organic colorants are derived from the basic hydrocarbon ring compounds benzene, naphthalene, or anthracene. Among the most important synthetic colorants for ink jet are those belonging to the azo, phthalocyanine, and anthraquinone classes.

I. Azo Colorants

The molecules of this class of pigments contain one or more azo groups (-N=N-) or (-N-N-); in addition, water soluble azo dyes will have a sulfonic acid group (-SO3H). Azo dyes are the most common dye molecule types in all four ink colors (yellow, magenta, cyan, black), and can be both water and solvent soluble. Red azo dyes can be responsible for very brilliant magenta hues, which, however, usually show very poor lightfastness.

II. Phthalocyanines

Phthalocyanine dyes are typically water soluble and have a high tinctoral strength. The molecules consist of porphyrin type rings, which will often have a metal in the center. Copper phthalocyanine cyan dyes are counted among the most brilliant and stable of dyes.

III. Anthraquinones

The dyes of this class are generally used in solvent based or hot-melt inks. They contain a double bond between oxygen and a carbon chain and thus belong to the class of ketones.

Chemically inert pigments employed in ink jet printing include carbon black, diarylide yellows, metal salt reds, phthalocyanine blues, and mono azos. Characteristic of these colorants are their highly symmetrical uncharged molecules which form relatively rigid, planar or near-planar structures. Intramolecular bonding forces such as hydrogen bonds form polycyclic ring structures, which provide protection against chemical reactions.

2. Inks for Ink Jet Printing

Ingredients of Liquid Inks

The following is a list of typical ingredients of liquid inks. As some ingredients serve multiple functions, their separate classification can be confusing.

Vehicle

Depending on the solubility characteristics of the colorant, the vehicle, a transport medium, typically consists either of water, a solvent or a mixture of solvents (solvent plus co-solvent), or water with added solvent. Glycols provide good solubility for many dyes and reduce the corrosion potential that can make solely water-based inks difficult to handle.

Colorant

Dyes in true solution or pigments in dispersion or a mixture of both can lend color to the ink. Typically, 5-20% of the ink will consist of colorants, the amount of which is termed “loading”. An ink may contain either one colorant only or a mixture of various dyes or pigments modified to result in the desired hue. Black inks, for example, will often incorporate colored dyes to correct a possible cool or warm tone. Some black colorants are designed by bonding a navy blue dye to an orange dye. Colorant particle size is of great importance, as it influences color saturation of the final print, lightfastness, transparency, and also functionality of the printhead. Typically, dimensions of the particles are kept within 1/20 of the nozzle diameter, e.g. 2 microns for a 40 micron orifice. Because pigment particles are large enough to scatter white light on their surface, whereas dye molecules are much smaller than wavelengths of visible light and thus do not scatter any light, inks with dyes are more transparent than those with pigments, one of the reasons why the use of dyes is more common in ink jet printing. The addition of a white pigment to an ink will modify its tint as well as reduce its transparency.

If the colorant in an ink is a pigment that has the same refractive index as the vehicle it is suspended in, light can pass through the ink without being bent, which increases the transparency of that ink. If, on the other hand, the respective refractive indexes are different, light will be scattered irregularly while passing through the ink, and the ink will appear more opaque. The greater the difference in refractive indexes, the more opaque the ink will appear; the less applicable it will be in color printing, in which hues other than the four process colors can only be achieved overlapping transparent yellow, magenta, and cyan dots.

The choice of vehicle restricts the choice of possible dyes, as a water based ink will only accept water soluble dyes, a solvent based ink on the other hand only solvent soluble ones. The waterfastness of the print is directly related to the choice of dye solubility. The choice of colorant is also restricted by the gamut - lightfastness dilemma: an ideal ink would have...
a wide color gamut and high light stability. In practice, though, dyed inks with wide gamuts show the least stability to light and UV radiation, whereas pigmented inks, which are more stable to fading, only provide for a narrow color gamut (Figure 2.7). Dyes can be differentiated by being either cationic or anionic, and this difference is of great importance in the development of an ink and of the ideal ink-medium combination, as is explained with an example further below.

A list of names and chemical formulas of typical dyes and pigments employed in ink jet inks, including a description of their strengths and weaknesses, would be a valuable resource for conservators, it does not, however, exist to this date. A compilation of information on commercially available dyes can be found in the Color Index, issued by the Society of Dyers and Colourants, Bradford, and the American Association of Textile Chemists and Colorists. It includes commercial names and suppliers of any dye currently in production as well as information on properties, color, and chemical structure of each dye. Dyes and pigments currently used in ink jet printing will have a Color Index (CI) number associated with their given name.49 Examples for the process color dyes used in ink jet are: CI Direct Yellow 132, CI Acid Red 52, CI Direct Blue 199.

**Surfactant/Dispersant**

Surfactants such as cyclic aliphatic diols, carboxamides (-CONH-), and micelles50 enable the dispersion of non-polar pigments in polar liquids or vice versa. Thus pigment particles can be suspended in a vehicle that would otherwise reject them to form an emulsion.

**Binder**

The ink binder is typically a polymer or a mixture of polymers with a fairly high molecular weight (2000-20,000).51 Its function can be film forming by polymerization, which must be prevented until the ink reaches the substrate, resulting otherwise in a clogged-up printhead nozzle. Cross-linking and the state of polymerization must be carefully balanced by the choice of solvent or co-solvent in the ink. Oxidation of the polymer causing scission must also be avoided, as this would change all of the ink properties depending on the viscosity characteristics.52 The polymer binder can also function as a mordant.

**Mordant**

One of the dilemmas that had to be overcome in the development of ink formulations was the desire to have water soluble dyes that are waterfast once they have come into contact with the substrate. Substances that anchor the colorants to a substance fixed to or part of the substrate are called mordants. In the case of an uncoated paper substrate, the mordant must have a certain affinity to both the dye and the cellulose of the fibers.

Cyclodextrin, for example, is a ring-formed molecule of dextrins with hydrophobic cavities which allows it to hold an equally hydrophobic (and thus waterfast) dye without interfering with the color of that dye. Cyclodextrin has a great affinity to associate with cellulose, as it is structurally and chemically very similar.

Another solution is to add certain amine groups to the dye molecule, to form a cationic dye. In contrast to most dyes, which are anionic, cationic dyes are more waterfast due to their increased interaction with the substrate. Boronic acid (B(OH)₂) can be added to the ink, as it has a high affinity for alcohols such as those found in cellulose. A dye can also be bound to a polymer binder, which is itself attracted to cellulose, or the functional groups of the dye can be modified themselves to enhance affinity to cellulose.53

**Humectant**

Humectants such as ethylene glycol and glycerol retard evaporation in the printhead, thus eliminating the possibility of ink crusting or nozzle clogging. Humectants also control the ink viscosity.

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51 Sarada and Cartin, p. 156

52 Ibid., p. 157

53 Gendler, p. 189
Additives

In order to modify the viscosity of an ink, which has a direct relationship to its jetting characteristics and drop formation, the following extremely finely ground substances, called extenders, can be added: kaolin (hydrated aluminium silicate), calcium or magnesium carbonate, silica aerogel (an almost pure, very transparent form of silica), or t alc (hydrated magnesium silicate). Calcium or magnesium carbonate will leave a dull surface to the dried ink, talc will give it a velvety finish.

Other additives can consist of molecules that act as light fading inhibitors. These have the purpose of relieving the excited colorant molecules of their excess energy without allowing them to change in structure or be subjected to cleavage. The energy can thus be transferred in the form of heat.

Further additives can include modifiers for surface tension and dye compatibility, defoamers, corrosion inhibitors, biocides, deodorants, penetrants/wetting agents, chelating agents, and others. Modifiers of pH keep the ink at a specific value in order to prevent dyes from precipitating out of solution and/or to avoid corrosion of the printhead by the ink.

Ingredients of Solid Inks

Prints made with solid ink differ from those made with liquid ink in that the image forming dot contains all of the original ink ingredients in a solidified state. Liquid ink prints, on the other hand, are designed to lose the vehicle and solvents of the ink by evaporation or absorption, and the resulting dot can be a variety of dye-medium interactive structures. Solid inks differ from liquid inks mainly in the choice of the vehicle, which must be solid at room temperature, but must melt when heated. The melting point can vary from barely above ambient temperature to a few hundred degrees centigrade. Tektronix phase change ink has a melting point of about 90 °C and must be heated up to about 130 °C to be jetted as droplets onto the medium. The vehicle is usually formulated from high molecular weight hydrocarbon esters and waxes. As an example for a typical solid ink, the ingredients of a Tektronix phase change ink are listed here.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Weight in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tetra-Amide</td>
<td>10-50</td>
</tr>
<tr>
<td>Mono-Amide</td>
<td>30-80</td>
</tr>
<tr>
<td>Plasticiser</td>
<td>0-25</td>
</tr>
<tr>
<td>Tackifier</td>
<td>0-25</td>
</tr>
<tr>
<td>Viscosity Modifier</td>
<td>0-10</td>
</tr>
<tr>
<td>Colorant (dye or pigment)</td>
<td>&lt;5</td>
</tr>
</tbody>
</table>

Due to the waxy nature of the thermoplastic vehicle, oil soluble basic dyes are needed for the ink. These dyes are naturally quite waterfast, but they tend to show a lesser lightfastness. In order to remain flexible on the medium so that the ink dots avoid flaking of the substrate when it is bent, plasticisers are typically added to the ink. Some hot-melt inks contain gelling agents, an example of which is carrageenan.

3. Further Considerations

Apart from the factors that determine the printability and compatibility of an ink as described above, issues such as shelf life, environmental impact, and product safety of an ink must be considered by the manufacturer. These are concerns that probably will not affect the work of the conservator directly, as the final print will contain no great amounts of solvents, which are most likely to evaporate during the drying of the print. The shelf life of an ink is influenced by problems of oxidation, increase or decrease of moisture content, ionic and non-ionic impurities, changes in pH, and more. As an example, IRIS Graphics Inc. Equipoise 3000 Magenta Ink may have the following "Hazardous Decomposition Products: May include oxides of carbon, nitrogen and sulfur, acrolein and other toxic fumes". Furthermore, the use of some colorants with excellent brilliance and lightfastness has been discontinued due to their toxicity and carcinogenicity.

3. Substrates

The substrate is the part of the medium that forms its structural base. It can stand alone or be coated with single or multiple layers in front and reverse. Paper is the most common substrate, but it is being partly replaced by a great variety of different materials. Some of the new materials and combinations are from common substrate design that has been in practice for other printing technologies, but some are being newly developed. Ink jet substrates can be divided into the generic groups of paper, plastic, paper-plastic combinations, and specialty media. The choice of materials used to form a substrate have great influence on the permanence of a print on that material. If non-permanent materials such as low grade bond paper or PVC are used in the design of a certain medium, the result can only be as stable as the weakest material involved allows it to be.

The substrate determines the weight, thickness, and strength of the medium. In order to be able to compare dif
ferent substrates on an objective basis, certain specifications can be defined. Those of Epson, Inc. are described as follows:

- **Basis Weight**: thickness per ream of paper in weight (eg. pounds per ream). A higher value indicates a thicker paper.
- **Opacity**: degree to which transmissive light is obstructed by the medium. A higher value indicates a more opaque medium.
- **ISO Brightness**: measure of diffuse blue reflectance from the medium. A higher value indicates a more brighter medium.
- **Absorbency**: time in seconds for the paper to absorb 0.01 mL of water. A higher value indicates a higher absorbancy capability. Coated papers absorb less water than uncoated papers.
- **pH Level**: degree of acidity or alkalinity of the medium on a scale of 0-14. A value lower than 7 is acid, one higher than 7 is alkaline, and one around 7 is neutral.
- **L*a*b* Color**: indicates the whiteness of the medium in the L*a*b* scale. L* stands for lightness. A higher value indicates a whiter medium.*

**Surface characteristics**

The surface characteristics of a substrate depend on the materiality of the uppermost layer of its structure. In the case of uncoated paper, this layer consists of cellulose fibers that have been either more or less smoothened out by pressure during calendering. Paper fibers that are less uniform and show a high relief under magnification will lend the surface of the substrate a dull matte finish, while fibers that have been pressed flat will give a glossy surface to the paper. If a coating is applied to a substrate, its surface characteristics can be modified by mechanically either smoothing out the surface or pressing in a texture.

**Formats**

Digital printers are currently manufactured to be able to print on any size ranging from snapshot to billboard format. The snapshot format was only recently introduced to the market and is aimed primarily at the amateur printers, who own digital cameras and are in keeping with traditional photographic formats. Banner media is used for advertising on the sides of buildings, for example, where rolls of printed banner are hung next to each other to make up an image that can thus have any width desired. In keeping with the factor of viewing distance, the larger the format gets, the lower the print resolution will need to be. Desktop printers adhere to standard formats that vary slightly in different parts of the world.

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Bond Paper

Bond paper (Figure 2.8) is specifically manufactured for use in desktop printers, photocopy machines, and for general office applications. It must therefore be widely available in mass quantities and at a low price, factors that usually do not allow for high-end permanence considerations. It is produced in many variations, among them bleached and unbleached, recycled, and colored, but the vast majority of all bond paper is manufactured as white, standard cut, individual sheets. It was recognized early in ink jet development that unsized paper allowed the liquid ink arriving at its surface to wick along the fibers. Bond paper can be sized with a variety of substances and is always calendered, thus decreasing undesirable ink wicking. In the paper manufacturing process, there is a distinction between internal and surface sizing. The most common internal sizing is that of the tree resin called rosin, which is mostly an organic acid containing carboxyl groups. To the rosin is added alum, or aluminium sulfate, Al₂(SO₄)₃, which helps its dispersion among the paper fibers. Rosin sizing typically leads to the build-up of acidity in paper over time. Internal sizing will increase the wet strength of a paper by strengthening the bond between individual fibers.

Surface sizing is added to modify the characteristics of the paper surface by sealing the surface fibers. Typical surface sizers are starches and gelatin. In addition, latex and a whole spectrum of combinations and synthetic substances can be used. The sealing of the fibers leads to a more uniform paper surface which is less susceptible to abrasion, an effect which can be enhanced by the process of calendering. The calender basically consists of two hot metal rollers through which the paper is pulled under pressure. The effect is that of further sealing and evening out the paper surface which visually results in a higher gloss. Further substances, termed additives or fillers, modify color, brightness, strength, opacity, and other characteristics of the paper.

Bond Papers for Ink Jet

Bond papers consist of a mixture of hard and soft wood pulp and contain lignin, and are thus not considered to be as stable as cotton rag content papers.

“Plain” Bond Paper

This is the typical paper utilized in photocopy machines, electrophotographic (laser) printers, and office environments. It is not recommended for use in liquid ink jet printing by the industry, as it is not specifically adapted to receiving liquid ink in a way that would render good image quality. Although the often incorporated calcium carbonate will absorb some water, the paper is always apt to cockle due to the amount of liquid applied to the medium in a typical ink jet printing process. This paper can, however, lead to good results in phase change printing.
II. Materials Analysis

Sized Ink Jet Paper

This uncoated medium can be considered a compromise between so-called plain paper and specially coated paper, as it integrates features of the receptor coating of the latter to the external sizing of the former (Figure 2.9). The paper is additionally sized with starches, poly(vinyl alcohol), or a combination of partly hydrophobic polymers such as alkyl succinic anhydride (ASA) and ketene dimers (AKD), which, apart from increasing the smoothness of the paper surface by filling in voids, have the function of a binder that will sustain the colorant at the paper surface and decrease ink wicking along the paper fibers. Another way to decrease wicking and increase dot sharpness is to add pigments such as calcium carbonate (CaCO₃) or titanium dioxide (TiO₂) to the external sizing, which tend to break up the random flow of ink along the paper fibers and also make the paper whiter.⁶³

Archival Paper

Papers that are more stable, or more resistant to the typical signs of paper deterioration, yellowing and embrittlement, are often termed "archival". The use of this word has been discussed extensively in recent times, and various definitions have surfaced. Independent of the terminology, and apart from environmental influences, two integral factors largely determine the stability of a paper: the source, quality and processing of the fibers, and the choice of sizing.

The main ingredient of paper is cellulose fiber, which can be obtained from a great variety of plants and can have distinct chemical structures and by-products. The most common fiber source is wood, from which a pulp is produced that is the basis for the paper. On average, wood consists of ca. 30% lignin, 20% hemi-cellulose, and 50% cellulose. Hemi-cellulose is not practically usable in paper making, and were one to remove the lignin as well, only 50% of the original mass would remain as usable. Wood pulp, which consists of both cellulose and lignin, has the economical advantage that most of the tree material can be utilized as ingredients for the paper. Lignin is an accelerator in the degradation of paper, though, so in order to produce a more stable product it must be removed from the pulp as well. The most stable paper is produced from cotton, which consists of α-cellulose, considered to be the most resistant fiber to oxidation and hydrolysis leading to chain scission. The higher the cotton rag content of the paper, the better its long-term stability. Paper made from chemically purified wood pulp, such as that used in fiber-based black and white photographic paper, is also suitable for long term archivability.

In the manufacturing of high quality, high rag content papers, the use of a rosin sizing would be counterproductive in that it would aid acidic deterioration in the long term. These papers tend to be internally sized with synthetic alkaline substances that enhance their durability by offering an alkaline reserve, or buffer. In addition to this, the paper can be loaded, or contain further buffer substances. The most common of these is calcium carbonate, CaCO₃, which is used to raise the pH of a paper. The use of further modification additives is more restricted among high quality papers than in bond paper manufacturing. High quality paper is often surface sized with either starch or gelatin.

"Archival" Papers for Ink Jet

Typical papers of this category are 100% rag watercolor papers with a rough surface texture of differing weight. These substrates usually feature a special surface sizing for ink jet applications that binds the ink, but does not alter the surface characteristics of the paper. One printing studio that has specialized in making IRIS print editions for artists, Nash Editions, in California, primarily recommends using these "archival" quality fine art papers. Their sortiment includes:

- Rives BFK white, 300g (31.5" x 47")
- Arches 260 lb, 356 g (25.75" x 40" cold press/hot press, 34" x 46" cold press)
- Arches 140 lb, 300 g (22" x 30" cold press/hot press)
- Arches 90 lb, 185 g (22" x 30" cold press/hot press)
- Somerset Velvet, 330 g (35" x 46.75")
- Somerset Rough Natural 500 g
- Somerset Rough White 500 g
- Somerset Textured, 500 g (35" x 46.75")
- Somerset Satin, 500 g (35" x 46.75")
- Arches 555 lb, 640 g (29.5" x 47", 34" x 46", 35" x 47" [...] )
- Museum Board, white, 2 ply, (32" x 40")⁶⁴

Further papers include Chesapeake, Spider, and Hammermill,⁶⁵ and various colored and translucent papers with or without adhesive backing.

⁶⁴ Nash Editions <http://www.nasheditions.com>
⁶⁵ AmeriJet <http://www.jetink.com>
II. Materials Analysis

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Coated Paper

By adding a coating to the surface of the paper substrate that is specifically designed to receive the ink of an ink jet printer, the image quality parameters can be controlled individually and with great precision (Figure 2.10). The coating can be tailored to suit the needs of a particular ink or be formulated for universal use, and can be added to almost any kind of substrate. Depending on the desired affect, the surface of the coating can be modified to render a glossy or a matte print. During the application process, patterned rollers can imprint a texture into the coating. Coated papers will invariably result in a better image quality, but ageing characteristics of the coating have not been explored thoroughly to this date (to the knowledge of the author), nor is the presence of a coating an indicator for the quality of the substrate. It can be assumed, however, that paper that has been coated will be of a higher quality than plain bond paper, since these media have been designed to achieve a better image quality. All plastic and paper-plastic combination media are coated, and so-called "photo-quality" paper substrates also feature an ink receptor coating. The functions and ingredients of the coatings are investigated in more detail in the following chapter.

2. Plastic Media

Since the introduction of the ink receptor coatings, the use of pure plastic substrates in ink jet printing has become practicable (Figure 2.11). The coating was necessary, because liquid inks would not adhere to the plastic sufficiently either to dry or to be abrasion resistant, as the liquid could not be absorbed by the substrate. Plastic substrates, also termed films, can have any degree of transparency, depending either on the method of manufacturing or the amount or color of pigments added. The key issue for image permanence in using a synthetic substrate is the choice of plastic used in manufacturing it. If a substrate is made of a plastic that is known to degrade in a certain fashion, it would seem senseless to print an image on it that is meant to last for as long as possible. On the other hand, if certain plastics have better characteristics for a certain application that only necessitates a temporary print stability, their use is justified. An important environmental issue to keep in mind when using plastic substrates is their biodegradability or recyclability.

Plastic Media for Ink Jet

Typical pure plastic substrates consist of single layer structures of polyethylene, vinyls, polyester and Mylar, Nylon, and Tyvek. Opaque plastic substrates have a white pigmented ink receptor coating. Transparent substrates, such as those used for overhead transparencies and translucent films used in backlit display cases, have a clear ink receptor coating. Some plastic substrates are sold with a one sided heat or pressure sensitive adhesive, which can be designed especially for their use in window displays.
3. Paper-Plastic Combinations

The effects of applying plastic films to a paper base have been tested in the manufacture of photographic papers. Resin coated (RC) paper has the great advantage that it does not soak up the chemistry contained in the processing liquids. This concept does not apply to the ink jet process, but RC paper has been adopted nonetheless, presumably because it lends the look and feel of a real photograph to a digital print (Figure 2.12). Furthermore, the use of an anticurling layer on the reverse of a base of paper keeps the print flat, even when moisture is applied to one side in the amount that it is in ink jet printing. A range of media has been developed that offers the structure of bond paper with either a plastic layer on the front, reverse, or on both sides. As bond papers consist of a mixture of hard and soft wood pulp, and are thus not considered to be as stable as rag content papers, the combination media could pose permanence problems not associated with archival papers. In the case of RC paper with a base of purified and lignin-free wood pulp, the paper itself will prove to be more stable, but RC based ink jet papers are likely to develop problems similar to those of photographic RC papers. Combination media are usually coated with an ink receptive layer.

Combination Media for Ink Jet

The largest group consists of RC paper, which comes in many brand names that almost always utilize the word “photographic”. A further medium is paper-backed polyester film, sold by Encad, Inc. Combination media are sold with or without adhesive backing.

4. Specialty Media

Once it had been found that the application of an ink receptor coating to a surface could convert virtually any material into an ink jet medium, the market abounded with different materials, a full listing of which is impossible due to the many variations. Among the more common are canvas, fabric, banner stock (fabric), transfer materials, floor advertising materials, and duplex (printable on both sides). Further specialities include substrates that are fire retardant\[^{66}\] and “Permafuse P-1233”, that is claimed to be 100% waterproof, 100% scratchproof, and 100% solventproof due to a curing step following the printing.\[^{67}\]

\[^{66}\] Milano, Inc. <http://www.milanoinc.com>

\[^{67}\] Permalite ReproMedia Corp.
4. Receptor Coatings

The development of ink receptor coatings brought the breakthrough to high image quality in ink jet printing as well as enhancing the range of usable substrates. Coatings enable high quality printing due to enhanced contrast, high color density, limited dot spreading with water soluble dyes, comparatively high water resistance, and variability in surface characteristics. Printing with aqueous inks on plastics, which would otherwise run and not be absorbed properly, also becomes a possibility, as the coating can absorb the moisture from the ink. Coatings also reduce print-through and cockling.

The goal of a coating is to keep the colorants on the surface of the print, in order to retain as much of the color density as possible for a brilliant image, while allowing the vehicle to disperse or be absorbed.

The ingredients of a coating can be specially mixed to fit a certain ink in order to result in the highest image quality. For this reason, it is generally advisable to follow the recommendations of ink and media manufacturers concerning the restriction to one brand name. As more and more products enter the market, however, this concept has become less important, and the ideal paper-ink combination can be determined for each separate application through testing. A second type of coating is designed to be universally applicable for a broad range of inks. They must meet many requirements, for which trade-offs in image quality and permanence must be made. Ink receptor coatings can be divided into two general groups, the single and the multiple layer coatings.

1. Single Layer

The typical composition of a single layer includes:

Active Ingredient
Dependent on the hydrophobicity or hydrophilicity of the colorant, the coating must be manufactured in a way that it can bind the dye and not repel it. This is mainly achieved by the choice of the active ingredient and binder. The active ingredients of a coating consist of a dye fixing agent (mordant) and moisture absorber, that are responsible for separating the colorant from the vehicle. In a layer containing hydrophobic latex and hydrophilic silica particles, for example, a non-polar dye dispersed in an aqueous ink will be bound to the latex co-polymers, while the water vehicle will get absorbed by the silica (Figure 2.13). A simpler version of this system employs only a structurally modified silica molecule. Functional groups of -NH\textsubscript{3} on the edge of the silica particles bind the dye while allowing the aqueous vehicle to pass by and be absorbed by the silica. Utilizing one of the above scenarios enables the colorant to stay precisely where it hit the medium, in this manner avoiding feathering. This mechanism has the further advantages that the print dries very quickly and that the colors are more intense due to the fact that the colorants are not distributed among paper fibers but rather rest near the surface of the print.

Binder
The binder is usually a combination of co-polymers that hold the active ingredients in dispersion. Typical hydrophilic binders are gelatin, polyacrylic, and poly(vinyl alcohol) (PVA). Hydrophobic binders employed are poly(vinyl chloride) (PVC), latex, polystyrene, and further polyvinyls. The hydrophilicity of a coating can be modified by precisely determining the amount of each binder in the mixture that is applied to the substrate. A certain type of coating, as described above, employs almost only silica particles, which imparts a matte surface to the medium. The silica layer is typically 20 µm thick\textsuperscript{68} but it has been found that alumina provides better surface coverage than silica at the same coat weight and serves its function of water absorption just as efficiently. Silica and alumina can only be employed in this manner for water based inks.

\textsuperscript{68} Sobotka, p. 306
II. Materials Analysis

Optical Brightener

In order to increase the contrast of the image and whiteness of the base, a white pigment, typically titanium dioxide, is added to the coating. Exceptions are the coatings applied to transparent films, which are necessarily without pigments.

Additives

As it is the coating that functions as the immediate environment for the dye after printing, its qualities are important for the issues of colorant longevity. In order to render the dye as stable as possible in the coating, many additives are dispersed in the polymer or gelatin of the binder. These include antioxidants, reducing compounds, and peroxide scavengers, all of which are designed to prolong the life of the dye by reducing the oxidation rate of the dye molecules. Aggregation promoting compounds encourage dyes to combine with others to form larger particles that are more lightfast. Triplet quenchers are energy absorbers that have the ability to receive the excess energy of an excited molecule in order that it might return to its ground state without causing any chemical changes either to its surroundings or itself. 69

Further Examples

The following (Figure 2.14) is an example for a single layer coating and its function in binding a dye. 70 The coating is made up of fine powder silica as a white pigment in a poly(vinyl alcohol) binder with mixed-in Polyfix 601 as dye-fixing agent. Polyfix 601 is a cationic polymer (polycation). The dye used in the experiments was the anionic dye Acid Red 249 in an aqueous ink.

It was found that the dominant state for the dye to be in was complexed with the polycation dispersed in the PVA. A small portion of the dye formed a solid deposit on the surface of the PVA where the polycation was present. Where not present, the dye dissolved completely into the PVA. When a cationic dye was used, it adsorbed onto the surface of the silica, either directly or complexed with the polycation.

In the experiments it was also found that silica can only be used to adsorb cationic dyes due to its negatively charged surface (it has silanol (- Si-OH) groups on its surface, which in aqueous solution have protolytic dissociation Si-O− making silica slightly acidic). As it adsorbs only cationic dyes, such as Methylene Blue, it repels anionic dyes.

In a talk from 1994, the positive results of ongoing experiments with an innovative type of coating for plastic substrates were presented. 71 A coating consisting of a regular mesh of microscopic, well-defined capillaries that are oriented perpendicular to the medium surface was developed. The ink, arriving at the surface, is drawn down the capillary, whereby the colorant is chemically bonded to the inside wall of the capillary and thus separated from the ink vehicle. The advantages of this system are a lesser dependency of the coating on the type of ink, a very high dot edge definition, and a reduction of smearing and scratching of the surface.

A specialty coating is offered by Canon’s BJC-7000, which applies a quick drying, water-resistant agent to the paper substrate moments before the ink hits it, which renders the paper waterfast. This can be interpreted as a form of lamination or coating.

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69 see also Chapter III. 3, Deterioration, Lightfastness
72 This illustration design has been adapted from that used in Oka and Kimura, p. 225
2. Multi-Layer

The capability of coating a substrate with a multi-layered ink receptor coating allows for incompatible additives or binders to be incorporated into one general receiving layer, in which each sub-layer provides a specific functionality and adds to the versatility of the coating. As the composition of the binder has a strong influence on the lightfastness of the final image, polymers that together cause instability but when separated are each beneficial to lightfastness can be incorporated into a multi-layered coating. Surface functionality and versatility layers can include agents for controlling lightfastness, waterfastness, adhesion, postprint curl, drying, gloss, wicking, anti-UV, static, friction, etc.

5. Laminates and Coatings

Due to the susceptibility to UV and light fading as well as the low waterfastness of all early ink jet prints, coating the print with a protective substance was a logical step, since its practice was well known from the printing and photography industry. There are generally two categories of applying a protective coat to a print: solid sheet lamination and liquid coating. Lamination basically consists of applying a sheet of plastic to one or both sides of a print and fusing the surfaces that are in contact with each other by means of heat, pressure, and/or an adhesive. Liquid coating consists of applying a plastic in a solvent to one or both sides of a print which then dries to leave a solid layer of the plastic on the surface. It is generally recommended not to laminate or coat valuable prints, since the danger of unwanted interaction between the laminate and the image forming dyes is present and as yet widely untested. In essence, the application of a laminate or coating means the practically non-reversible placement of a foreign substance in intimate contact with the print surface. A visual and haptic consequence of lamination is a change in surface characteristics and a “plasticy” feel to the treated print. Usually the surface is rendered glossy, but a dull matte or a glossy matte effect can be achieved and there are also specialty surfaces such as imitation canvas and parchment.

Laminates and coatings have a long history in the printing industry, and the applications and combinations are manifold. The reasons for laminating a printed substrate include: providing surface gloss, resistance to handling, chemicals, abrasion, and barriers to water, fungus, dirt, gases, air, or UV radiation. Barriers to chemicals are designed for oxygen, pollutants, oils (e.g. fingerprints), soaps and solvents, to name a few. Pollutants that attack dyes include peroxides, hydrogen sulphides, and sulfur dioxide, all of which cause oxidation. “Squalene resistance” is a term used to express the resistance to the test oil squalene which simulates the oils found in human skin and animal fats. In product packaging, laminates such as poly(vinylidene chloride) are used as an oxygen barrier and poly(vinyl alcohol) as a moisture vapor barrier.

Pressure sensitive plastic sheet laminates (also termed cold-mounting) have an acrylic adhesive on one side. They are applied with pressure to the document, usually in the form of rollers. These laminates have been used extensively in coating small documents such as identification badges and licenses, and were introduced to the field of commercial photography around 1980, where their application in protecting and presenting large format display prints was appreciated. Pressure sensitive glossy surface laminates in the U.S.A. are typically made of polyester, and in Europe polypropylene is also employed. Semi-matte and matte laminates are generally made of poly(vinyl chloride).

Heat sensitive laminates consist of a thermoplastic substance that is manufactured in solid sheets and applied to a print under high pressure and heat. Heat set laminates can also incorporate an adhesive to enhance or modify their adhesion qualities. In practice, the plastic is heated up to the minimum temperature at which it melts enough not only to adhere to the surface of the paper but also to penetrate the pores of the paper fibers. This penetration is the distinguishing factor to the solely pressure sensitive plastic sheet laminates, which only adhere to the surface of the print or document. Heat set laminates require either heated rollers or a heated press. Temperatures depend on the choice of plastic but can reach quite high values. After the heating step the laminate must be cooled down in order to set. The surface characteristics of the laminate are determined by the smoothness of the surface of the roller or metal plate of the laminator. Thermoplastic polymers include polyethylene and polypropylene.

Contemporary pressure and heat sensitive laminates will generally incorporate UV absorbers, which, though redundant in combination with photographic color prints, serve a greater purpose with ink jet hardcopies, which to date have little UV protection of their own.

In addition to sheet laminates a print can be protected by coating it with a liquid that will solidify as a transparent layer. In the printing industry, these liquids are termed coatings, in contrast to the laminates. Coatings can include varnishes, lacquers, UV cured coatings, and aqueous coatings. Varnishes are vegetable oil formulations that air-dry. Lacquers are solvent-based and dry to a high gloss, but they often lack good adhesion and flexibility. A common lacquer in the past has been cellulose nitrate, or nitrocellulose, which, as well as shellac, provides squalene resistance. UV coatings show a

high gloss, offer good protection to UV radiation, but require expensive curing equipment. These liquid coatings contain no solvents, but instead molecules that are polymerized by UV radiation to form a thin, transparent, flexible, solid film. The coatings offered by 3M marketed as Photogard Film Protector and Print Protector are made of silane. Aqueous coatings such as acrylics, shellac and urethane resins are gaining popularity in the printing industry, since the environmental issue of solvent vapors can be avoided. Further liquid coatings include wax and polyethylene emulsions, which are primarily applied in food packaging. One coating frequently used on ink jet prints is the spray-on IRIS PrintSeal, which has the listed ingredients: "Dimethyl Ether, Isopropanol, Isobutyl Acetate, Coating: Trade Secret".

In commercial photography studios, prints are sometimes sprayed with a UV protection lacquer which typically consists of cellulose nitrate dissolved in a mixture of solvents, plasticisers, and often matting agents. Although color RC prints do not need an extra UV protection, since the paper is manufactured with a built-in UV resist coating, the lacquer provides an even surface that can cover up changes in surface gloss due to retouching. It has been found that the UV protective properties of these coatings generally do not extend the life of image forming colorants.

Lamination for Longevity?

In the history of paper conservation, lamination of documents has also played a role. As early as 1938, the one-sided lamination of documents with cellulose acetate film had become practical and acceptable as a preservation treatment. Developed by W. J. Barrow, who had searched for a method of extending the structural stability and enhancing physical protection of documents as well as filling in holes and tears, the lamination method was soon extended to seal both sides of a given paper object. The Barrow Lamination Process was incorporated into the treatment repertoire of the Preservation Office at the Library of Congress, Washington, DC, by the early sixties. It included the step of deacidification prior to lamination with heat sealed cellulose acetate lined with strong fibered tissue paper. Although controversial from the beginning, later critics mainly only attacked the use of insufficient deacidification rather than the lamination itself.

In 1976 the Library of Congress issued a statement regarding a change in opinion about the process of lamination as a preservation measure. The damage to the document and irreversibility associated with lamination were recognized as reasons to consider the use of encapsulation in polyester film as a preservation method, at least for those documents that merited treatments for long term preservation. For documents that were categorized as requiring less than archival preservation, the Barrow lamination remained the primary treatment. The advantages of the encapsulation process were manifold. Polyester is a much stronger plastic than cellulose acetate, it does not deteriorate as does acetate, and the encapsulation can be cut open without any harm to the document, thus allowing further treatment if necessary. It was believed that the documents underwent some kind of deterioration due to the 340-360°F heat of the laminator, and a darkening or yellowing of some documents had often been observed. Furthermore, some documents had become brittle inside of the lamination, perhaps a result of cellulose acetate deterioration. Encapsulation required neither heat nor pressure and proved to be a reversible treatment that is still sometimes employed today. The lamination procedure was finally dropped soon after this publication and is not considered a beneficial treatment in the field of conservation today.

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75 Ibid., p. 146
76 W. J. Barrow, The Barrow Method of Restoring Deteriorated Documents, (Richmond, Va.: Barrow Restoration Shop, 1970), pp. 8-13
A further method of lamination that was being used in paper conservation consisted of the solvent lamination process that was developed at the National Archives in New Delhi, India. Using acetone, the document was adhered to cellulose acetate films, which would temporarily dissolve in the solvent. The final package, consisting of a sandwich of tissue paper on the outside and cellulose acetate in direct contact with the document, would be pressed without heat until all of the solvent had evaporated and the laminate had set. This is also a method which to the author’s knowledge is not in general practice any longer.

Lamination of Ink Jet Prints

For ink jet prints that are used in advertising, such as banners, posters, backlit display cases, and floor graphics, any benefit that laminates or coatings will bring are appreciated and well suited to the purpose, since they achieve short-term protection that is beneficial for the designated lifespan and purpose of those prints. A fine art hardcopy that will either be exhibited in controlled lighting or be carefully housed in a collection of prints will not necessarily need the brute protection of a laminate. In order to avoid any as yet unforeseen complications that might arise with the long term intimate contact between a plastic and the vulnerable ink used in ink jet printing, not to mention the largely irreversible character of the physical fusion of a plastic with paper fibers, it might be wiser to avoid laminates or coatings altogether. Depending on the way their work is being displayed and handled, however, some artists might chose to laminate their prints. Photographer Markus Seewald, for example, printed thirteen 15x24" images on ink jet paper, which he then had bound to a book. In order to protect the images from the physical wear of turning the pages as well as from fingerprints and moisture, he had the prints heat-set laminated on the image side by a conventional printing business. The laminate consisted of polypropylene and it was applied with heat, pressure, and an incorporated adhesive. Seewald’s concern for immediate danger to his work outweighed that of possible long term degradation consequences to his images.

The laminates and coatings used for protecting ink jet hardcopies are basically those that are used in the printing and photography industry, as described above. They are offered in various thicknesses, but the range is mostly from 1.6 to 3.0 mil. In addition, the author has encountered:

- Teflon® (DuPont), made especially for outdoor displays and boasted to be cleanable even of graffiti due to chemical inertness to cleaning solvents. Pressure sensitive.
- PVC, Polyester, Polypropylene (Ilford),
- Tedlar®, Lexan® (Neschen),
- Elam® (Coda Inc.)

A specialty is offered by Permalite Corp.: an ink jet medium named Permafuse, which apparently fuses after being printed on to result 100% water-, scratch-, and solvent-proof. Textures and or gloss can further be added. Another specialty is offered by Canon’s BJC-7000, which applies a quick drying, water-resistant agent to the paper substrate moments before the ink hits it, which renders the paper waterfast. This can be interpreted as a form of lamination or coating.

III. Preservation Issues

1. Introduction

"Subject: Re: Print Longevity
Date: Mon, 19 Oct 1998 15:42:19 -0700
From: Jack F ...
Reply-To: epson-inkjet@leben.com

>I'm using the Epson 1500 for color work, making prints with
>customers' photos, laminating the print, and placing under
>glass. Is this print going to fade in two years in normal
>household light?

That's probably the case. Lamination doesn't seem to
help with fading, and glass doesn't help either; according
to the experience of those that have tried such things, the prints
will fade no matter what you do. Some inks fade faster, some
papers combined with some inks seem to resist fading longer
than others. But some fading will be apparent after one to
two years if the prints are kept in the dark (eg, in folders or
whatever). If they are displayed under normal room lighting,
some fade (or shift colors) in a few weeks, others a few
months. There are some inks that have recently become avail-
able that are supposed to be more archival than the standard
inkjet inks, but response has been mixed. Most seem to com-
plain that they may last longer, but the color gamut is not as
great. The technology is not quite where most of us would
like it to be.

Jack F ...

Preservability of ink jet? The main concern in the long
time stability of ink jet prints is their relatively weak light-
fastness. From the beginning of the ink jet era this has been a
curse that only a small proportion of ink jet printing is used for
outputting photographic images? It is understandable that
photography has become a measuring stick for ink jet image
quality and stability due to its overwhelming dominance in
contemporary imagery. Furthermore, many ink jet applica-
tions have begun taking over traditional domains of photo-
graphy. Apart from the question if it looks like a real photo-
graph, the concern if it will last as long as a real photograph
has become an important issue for users and manufacturers
alike. Much of the advertising for new ink jet products stresses
the merits of improved lightfastness. Other conservators are
regarding the present state of development as a unique op-
portunity to investigate and take direct influence on perma-
nence issues of these contemporary printing processes.

There is also the issue that until now as a trade-off for
more permanent inks, which are usually pigmented instead
of dyed, the color gamut of the print is reduced. Even dyes
that are more lightfast tend to be less brilliant. This can turn
out to be a serious problem for an artist using ink jet techno-
logy as his choice for output, and he may prefer to achieve a
brilliantly colored print that might not last as long rather than
a less colorful print that will be more stable. Nash Editions, a
fine art printing studio based in California, describes the con-
siderations it has had with its customers:

"The whole issue of permanence is only one consider-
ation in choosing an ink set. His [Henry Wilhelm's] testing
process DOES NOT take into consideration the color space of
the ink set being tested. Theoretically, one could submit four
bottles of the most permanent ink component available (e.g.
four bottles of Lyson High Intensity Fine Art Black) and label
them Cyan, Magenta, Yellow & Black. The permanence test
would be spectacular, however, printing an image with this
ink set would be disastrous on an aesthetic level. Nash Edi-
tions finds the magenta component of all of the so-called
"permanent" ink sets to be lacking. They can be marginally
useful when printing on coated surfaces, but on untreated
fine art watercolor papers they reproduce red as a brick-red,
with more orange than red.

In 1993 as the first iteration of the Lyson fine art ink set
became available we made a deliberate, aesthetic, decision
to use a much less permanent but vastly superior (in color

79 Epson - Inkjet mailing list, epson-inkjet@leben.com>
space) magenta component which was manufactured by American Ink Jet ...

An IRIS print must not be judged on permanence alone. Art is not about permanence, art is about aesthetics and vision. Is a watercolor less of an artistic expression because it is more fugitive than an oil painting, or is a C-print less meaningful because it is less permanent than an IlfaChrome? [sic] Artists rarely pause to consider permanence when inspiration strikes. Photographer and painter David Hockney commented specifically on the permanence of IRIS prints by simply stating that "colour is fugitive in life, like it is in pictures, indeed colour is the most fugitive element in all pictures, a great deal more than line. Dimming the light alters color. It does not alter line."80

Ink jet processes involve highly complex chemical and structural systems that are difficult to identify and analyse. Furthermore, the possibilities of their combinations are endless. Due to these factors, many researchers and conservators have decided to dedicate their resources to the processes and materials that seem most promising. As it turns out, this approach includes the processes that utilize materials that have been known to the conservation community for a long time, such as high quality paper. Due to the novelty of ink jet preservation experience and research, this chapter should be regarded as a collection of issues and research proposals that are worth the effort of extending and investigating. In this sense, no directly applicable recommendations have been included that describe housing, exhibition, and treatment of ink jet prints. It is thus advisable to be overly cautious when dealing with hardcopies, and to adhere to the guidelines tested and set out for the most sensitive of materials encountered in conservation.

2. Testing for Permanence

One of the great difficulties in investigating stability issues of ink jet hardcopies is speed at which products are developed and changed without notice by the manufacturers, the multitude of products available and their many possible combinations. For this reason it is wise to distinguish between those prints whose stability is worth lengthy investigation and those that are destined to serve a specific purpose for a set period of time and then to be expendable. Prints are produced in a specific context which should determine the expectations of its stability. This is the path that has historic precedence and that has been adopted by most testing institutions. The concentration on few, promising technologies and materials also has the consequence of the possibility of having an influence on the industry that is behind it in the sense that material permanence issues can be pushed.

Test methods for object permanence include a simulation of the actual use of the object in real life by using elevated conditions of heat, humidity, light, air, and pollutant levels. Resulting changes are measured, compared with the original data, and the differences are extrapolated from the elevated conditions at which they occurred to normal conditions. Thus the resulting predictions can be used for the actual use of the object. Testing methods for ink jet hardcopies have been derived from those of color prints, as both are related in use and image forming substance.

1. Standards

The American National Standards Institute (ANSI) develops test methods for product evaluations. The ANSI IT9-3 subcommittee has developed a standard methodology for the testing of the light- and darkfastness of color photographs: IT9.9-1996, American National Standard for Imaging Media - Stability of Color Photographic Images. This standard regulates the preparation of samples for testing, the properties of the testing equipment, five test scenarios, necessary features of the test image, and the scope and properties of the resulting data. The five different light and environment conditions are: simulated outdoor sunlight, incandescent room light, fluorescent room light, simulated indirect daylight, and intermittent tungsten lamp slide projection. The Technical Committee IT9, Physical Properties and Permanence of Imaging Materials, is currently working over the testing methodology developed for the IT9-9 standard in order to adapt it for a new standard that will apply more directly to digital hardcopy materials. Considerations for image stability tests that will be new for a digital hardcopy standard include waterfastness, outdoor weathering, fingerprint, and image transfer tests.81

2. Testing Institutions

Image Permanence Institute (IPI)

The Image Permanence Institute, situated at Rochester Institute of Technology, Rochester, NY, has one of the best internationally known testing facility for imaging materials, and has been concerned with stability problems of digital imaging products for some years. The main testing areas are lightfastness, dark stability, physical properties, and pollutant resistance. Scenarios include outdoor and indoor weatherability simulation and various lighting situations. Physical tests...

80 Nash Editions <www.nasheditions.com>

81 Photographic & Imaging Manufacturers’ Association <www.pima.net/it9.htm>
developed specifically for ink jet hardcopies include waterfastness (drip, immersion) and image transfer due to high RH, pressure, and heat.

Wilhelm Imaging Research (WIR), Inc.

Wilhelm Imaging Research (WIR), Inc., has a long history of image stability testing and has begun on the endeavor of testing digital imaging materials. WIR is doing much research on the stability of IRIS Giclée prints, as this process is still the primary hardcopy option for artists’ digital printing.

Manufacturers

The companies that manufacture components of the ink jet process such as ink and media are very concerned with the permanence of their products, because they have come to realize that the users value more stable processes over less stable ones. A look at current advertising for ink jet products will easily confirm this concept. The exemplary testing facilities at Ilford AG, Switzerland, where the Ilford ink sets and media are produced, conduct extensive research on the light- and waterfastness of Ilford products as well as those of the competition. Through comparative tests the own products can be evaluated in the scope of the market as a whole. Utilizing the same media in various printers with various inks, for example, allows its compatibility to be determined. Accelerated light exposure tests lead to results that can be used to put together a product profile, and a database is being built up that any conservation scientist or researcher would envy. Scientists and engineers from the industry are also members of the ANSI committees that work on testing standards, as they not only have the technical background and proximity to the processes but also an interest in achieving test results that might help them improve their products.

For media that are designed for use outside, such as advertising banners, so-called natural weathering tests are common. The prints are subjected to outside conditions, which include sunlight, moisture in the form of dew and airborne humidity, temperature fluctuations, biological growth, chemicals, and pollutants. Two such natural weathering decks are available in Miami, Florida, and Phoenix, Arizona.

Independent Conservators

Andrew Robb, Photograph Conservator at the Library of Congress, initiated a series of waterfastness tests on IRIS prints. The tests have begun are surely only the beginning of many necessary experiments, as until recently IRIS prints had mostly only been tested for their lightfastness.

The conservators Bertrand Lavédrine, Martine Gillet, Chantal Garnier, and Martine Leroy, of Paris, performed a series of lightfastness tests on ink jet and photographic materials using the methodology described in the ISO norm 10977 (1993). Measurements were made with both a traditional densitometer and a spectrophotometer, and results showed a comparative lightfastness of six different materials.82

Specialist Magazines

As ink jet has become tremendously popular among amateur printers and everyday computer users, stability data is of general interest to the public. Periodicals that specialize in computer technology, photography, and digital printing strive to offer their readers information and recommendations concerning the permanence of ink jet hardcopies. In one example, the magazine “ComputerFoto”, a German periodical dedicated to digital imaging, had the facilities of Ilford Switzerland test 25 different ink jet media which had been printed on four different printers.83 Accelerated dark and light stability tests were done and the results published. Although not as thorough and detailed as large scale testing done on a regular basis by the industry and by testing institutions, this project made test results available to the greater public, which might have had difficulties accessing similar information otherwise.

3. Stability and Deterioration

The difficulty of assessing deterioration manifestation is that the many substances and layering of materials in inkjet hardcopies complicate their preservation. The ink, for example, cannot only be regarded by itself, but must be viewed in context with the coating and paper materials embedding it. Generally speaking, there are internal and external influences on the stability of image forming substances. Internal factors include substances that make up the object, such as the ink receptor layer, the colorants, and other substances that stem from the ink or the substrate. External factors consist of the temperature, relative humidity, pollutants in the atmosphere, intensity and type of light, as well as the printing pattern. The general rule of substance stability implies that a high energy content of a molecule leads to high chances that it will change. In consequence, substances are most stable in low energy situations.

1. Temperature, Humidity, and Atmosphere

High temperatures and relative humidity (RH) levels enhance the reactivity potential of molecules, and should thus

be avoided in storage and display situations for ink jet prints. High temperature of a substance can be understood as the measure of kinetic energy of a molecule: the higher the vibration energy of that molecule, the higher its temperature. As has been stated above, energy rich states enable the degradation of molecules through cleavage or chemical reactions with neighboring molecules. Humidity allows molecules to move and thus come into contact with each other, in this manner further enabling chemical reactions.

Low temperatures might be a cause of deterioration of plastic substrates, which can become brittle. If a substrate contracts at a faster rate than does a coating, the resulting stress might lead to cracking of one of the layers. The flexing or any impact at low temperatures might enhance this problem.

Airborne substances such as ozone, peroxides and pollutants will attack colorant molecules primarily at their weakest point: the double bonds, which are responsible for color formation. Oxygen in the air might accept energy from a dye excited by light, in this manner forming a chemically aggressive singlet oxygen, a strong oxidant, that has the capability to break double bonds and thus either ruin or diminish conjugation lengths.

Among the testing conservator Andrew Robb has been doing on inkjet prints, the susceptibility of IRIS prints to changes in RH has been an important issue. Samples were subjected to an environment of 100% RH, which led to an overall magenta shift due to the bleeding and thus spreading of the individual dots of magenta ink. This can be seen in an example from the ComputerFoto test results (Figure 3.1).

2. Waterfastness

Andrew Robb has also performed tests to determine the sensitivity of the Lyson Fine Art inks on Somerset Velvet paper to direct application of moisture and select solvents. The results showed that while water directly applied to the print would immediately smudge the dyes, the solvents ethanol and toluene did not dissolve any dyes, but resulted in a slight change in image appearance. Robb suspects and has recently confirmed that the optical brighteners that the substrate has been sized with or which are present in surface coatings will tend to migrate in the presence of moisture, which could lead to staining of the paper when the brighteners begin to lose their power due to excessive light exposure.84

The waterfastness of the print is directly related to the choice of dye solubility: a dye that is water soluble will show a high affinity to dissolving in any moisture applied to the

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84 talk at the AIC Photographic Materials Group meeting in Boston, MA, March 13, 1999
print, which can cause migration of the dye molecules in the substrate (Figure 3.2). On the other hand, this dye is most likely to show good smudge resistance to non-polar solvents. A dye that is oil soluble, such as one employed in hotmelt ink, will prove to be highly waterfast, yet susceptible to dissolving in certain solvents. Pigments such as those used in inks for banner prints for outdoor usage have proven to show high waterfastness due to their insolubility (Figure 3.3).

One method of enhancing the waterfastness of a water soluble dye, and thus of prolonging its life once on the substrate, is to replace the typically water solubilizing sulfonate (SO$_3^-$) functional group with a carboxylate group (CO$_2^-$). The further inclusion of a polymer such as a polyamine in an ink can enable the forming of a bond between the cellulose of the paper substrate and the dye, thus also increasing the waterfastness of the image. The importance of a chemical bond between the colorant and the substrate for image permanence must be stressed, as a strong bond enhances not only waterfastness and lightfastness, but also mechanical stability of a print.

3. Light- and UV-Fastness

The term lightfastness is used to describe the ability of a substance to remain stable during exposure to light or to the electromagnetic radiation near visible light, such as UV. Typical results of weak lightfastness are fading of colorants and staining or yellowing of other substances such as paper (Figure 3.4). The lightfastness of a printed ink jet image depends mainly on the choice of the colorant in an ink, but it is also a result of the immediate environment of the ink particles, such as an ink receiving layer. The combination of these two factors will determine the resulting lightfastness of a print, as can be seen clearly in the lightfastness test results of various papers printed with one ink set, which are published in the magazine ComputerFoto: whereas the ink is relatively stable on one medium, it fades on another to a great degree (Figures 3.1 and 3.4). As light can vary greatly in composition and intensity, it should also be noted that images can react differently in differently illuminated environments.

The choice of application usually determines the lightfastness requirements, which in turn has an influence on the choice of printer and ink. Indoor applications almost always use dye based inks, whereas large format printers for outdoor and advertising applications will usually employ the more light stable pigmented inks. In the discussion concerning the choice of either dyes or pigments in an ink it should be noted, however, that no colorant, be it pigment or dye, is completely stable in light, but rather, that on a scale, some colorants are just less lightfast than others. In all of the publicity given to UV protection and ink jet stability, the fact is generally neglected that dyes will not only fade due to UV, but also to a large extent due to the effects of visible light. The prevalent energy-rich UV radiation of 200-400 nm is the wavelength range that primarily causes photochemical reactions and bond rupture in organic compounds. Next to the fading of the dye itself, the size of the image forming ink dot on the medium has an influence on its lightfastness. The smaller an ink dot, the more surface area relative to its mass it has exposed, thus the more it can react with other substances. According to the company Magellan, the double strength ink which is offered in their catalog of products employs higher concentrated colorants which should result in better fade resistance. The concentration of colorant in an ink drop will also affect its lightfastness.

As described in Chapter II. 4. Substrates, the ink receptor coating can consist of various layers made of different polymers and integrate a host of additives. It has been shown that this coating can be prone to stain yellow in unprinted areas of print media through excessive exposure to light. The reactions between the colorants and the substances in the coatings are typically of reductive and oxidative nature. The largest role in the issue of light stability, however, is played by the colorants themselves.

Colorant Fading

The photolytic deterioration of organic colorants is the main factor for the fading of ink jet prints when exposed to light and UV radiation. As an organic molecule such as an ink jet dye

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85 Gendler, p. 189
87 Seewald, pp.44-45
88 Wilhelm p. 145
89 Brill, p. 10
90 Magellan Materials and Supplies, Inc.
91 Seewald, p.47
absorbs energy from light with the result of producing color, parts of the absorbed energy may cause heating up of the molecule, while the rest may initiate a chemical change in the molecule. In the cycle consisting of absorbing energy (advance from ground state to excited state) and releasing energy (return to ground state), the colorant will for the most part return to its original state without any change to its molecular structure. The more often this happens, however, or the longer the molecule is exposed to light, the higher the chance that the dye might change its molecular structure when returning to ground state, which could result in a modification of its color absorption characteristics.

A chemical reaction necessitates an initial amount of energy that is sufficient to cause a change in a molecule. This energy is termed the activation energy. In the case of the organic dye molecule, this change could consist of the breaking of a bond by the absorption of light. If a double bond is broken, the conjugation length of the molecule is reduced, and the color absorption capabilities are disturbed, either leading to a loss of its absorptive and reflective capabilities which is perceived as fading, or leading to a shift in wavelength absorption which results in a color shift (Figure 3.5). The complete rupture of a bond (cleavage), such as is possible with azo groups (-N=N-) leads to the division of the molecule into two smaller ones, which will each have shorter conjugation lengths.

In a theoretical example, a blue absorbing, magenta reflecting azo dye, which absorbs wavelengths around 450 nm, can be cleaved at its azo group, resulting in two distinct molecules that absorb only in the 225 nm range, which consists of UV radiation. As a result, all colored light is reflected, which the eye perceives as white. The individual activation energy can be determined for each dye and pigment, giving the ink developer an idea of its capability of withstanding light over time.

Among the various types of photofading mechanisms, the most common is the photo-oxidation reaction, which, by means of peroxides, radicals, and singlet state oxygen, can lead to the degradation of dye molecules. In the presence of atmospheric moisture a series of oxidative reactions can completely break down an azo dye into two or three products that have different absorption characteristics from the initial molecule.

Of the three color dyes mostly used in ink jet, yellow, magenta, and cyan, the magenta dyes have continued to be the least light stable. Cyan inks typically use dyes of the phtalocyanine class, as these have been found to be most stable. Yellow dyes have been noted to be most lightfast, as they have the shortest conjugation length, and thus the least probability of molecular changes during the cycling from ground state to excited state and back. As yellow dyes also absorb the highest energy light, that of blue, they can easily pass off the energy to surrounding molecules without harming themselves. Magenta and black dyes have long posed stability problems, which was a reason for many companies to investigate the possibilities of using pigments instead of dyes. The best magenta dyes to date are of the class of azo dyes, although even in this one class the stability can vary greatly.

An excited molecule is more chemically reactive, as it has excess energy that it needs to get rid of in order to follow the rule of returning to a relaxed, energy-poor state that governs all chemical reactions. In its excited state, a colorant will readily react with any electron receptor in its vicinity by donating the excited electron and thus modifying its conjugation length, which would lead to the effects described above. One such example is apparent in the case of overlapping dots of ink on a substrate, especially obvious in green areas such as grass. The green hue is an effect of overlapping cyan and yellow dots. Two reactions lead to the fading and yellow shift of green. Firstly, but less relevant, the cyan dye has a longer conjugation length than the yellow dye, so the chances of its cleavage are greater. The breaking up of the conjugation length of a cyan reflecting dye tends to leave two yellow reflecting colorants in its place. Secondly, and more common, the yellow dye, absorbing high energy blue light, will readily transfer its energy to the cyan molecules it is in direct contact with. This step, termed energy transfer, or photo-catalysis, can also lead to the cleavage of the conjugation of the cyan dye, mostly at the azo group, resulting in the same effect of loss of density and yellowing of the green grass. It has been found that single dots of ink are more stable than overlapping dots, mainly due to the factor of energy transfer.

The highly reactive excited molecule can also react with substances in the receptor coating, which demonstrates the

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93 interview with Scott Williams: the "grass effect" (Nov. 16, 1998)

94 Ibid.
importance of the direct environment of the colorant in or on the medium. Many experiments have been made with the integration of electron receptive substances in the ink jet coating that might allow the colorants to return to their ground state without damaging themselves in the process. Coatings that contain substances not compatible with a given colorant may accelerate their fading and color shifts. As a result, the combination of ink and media is a critical factor in the longevity of a printed image.

The difference between pigment and dye fading depends in part on the size and the relative surface area of the colorant. Pigments are actual crystalline particulate of which only about 10% of the dyes that make up the crystal are on the surface. Not only can the vast amount of internally stacked dye molecules in a pigment assist in the dissipation of the energy of the photo-excited molecules on the surface, but already photofaded surface molecules can also act as a light barrier for the internal molecules of the pigment crystal, thus protecting the whole colorant from further fading. Dyes, on the other hand, because they exist in a monomolecular state, are smaller than pigments and thus have very large relative surface area, which is vulnerable to chemical and physical attack. Once photofaded, a dye cannot contribute to optical density any more. Pigments vary in their lightfastness depending on the internal structure of their particles. If a pigment is composed of large crystals that are free from defects, it will probably have a higher lightfastness than one that is composed of aggregates of minute crystalline structures.

Print fading also includes internal reflectance mechanisms that depend on drop size and density in combination with choice of medium. In IRIS prints, it has been found that very light areas, such as those found in flesh tones, fade at a faster rate than denser areas that are more heavily inked. In experiments conducted at IRIS Graphics Inc. to determine the cause of this phenomenon, it was found that light that was reflecting off the bright material of the medium directly surrounding the printed dot would accelerate its fading, particularly at the dot edges. Therefore a smaller (and thus lighter) dot, which in IRIS prints is made up of few individual droplets, would fade at a faster rate than a larger (and thus denser) dot, which is made up of many droplets. Comparing printed dots on reflective media and transparent film, it was found that the same dots printed on transparent film backed with black paper faded less than those on reflective media due to the lack of reflecting substances in the immediate environment of the dots.

4. Substrates and Coatings

Next to image deterioration, the longevity of the supporting medium is of equal importance in the preservation of an ink jet hardcopy. If the colorants of a print are extremely stable, but the paper they are printed on deteriorates rapidly, the overall image quality and the integrity of the object will suffer. In the case of paper substrates and RC based media, much is known about chemical and structural deterioration from the fields of photograph and paper conservation. The knowledge of plastics permanence might also be able to be applied to the pure plastic substrates used in ink jet processes. However, when the presence of the ink receptor coating with its complex mixture of binders and additives is taken into account, the prospect of permanence testing and research becomes daunting. It is partly for this reason that it is largely recommended to print documents that are to be valued in the long term on thoroughly tested, well known, high quality, and uncoated substrates such as 100% rag content artists’ paper.

In an Epson Inc. listing of ink jet media the pH level of each is given, and out of ten products, eight prove to be of acidic nature, with values ranging from 4.3 to 5.8. Only two are listed as having a pH that is higher than 7, at 8.3 and 8.6. It is unclear from the context, however, exactly how the testing was performed, and if the ink receptor coatings on the surface of the substrates were tested or rather the substrate itself. An alkaline environment might increase the lightfastness of a print, but it could also reduce the color gamut. As the image quality is the current driving force in sales, manufacturers are reluctant to trade off color for permanence. It should also be kept in mind that the majority of paper based ink jet media on the market today utilize a high percentage if not 100% wood pulp as a fiber source.

Coatings can either be formulated to specifically suit one type of ink, or they can be designed to be universally applicable. The former is more likely to enhance the archival quality of an ink jet print, as it can contain substances that are specifically placed to strengthen the lightfastness of the inks it has been developed for. The latter coatings, typically found on third party media, are developed for a broad range of inks. They must meet a broad range of requirements, for which trade-offs are made. If these trade-offs are detrimental to the longevity of the colorants or the media, substrates with these coatings cannot be recommended for prints of archival value. Little is known of interactions between the coating and the substrate in environments of high humidity and temperature. Problems have arisen with the structural stability of coated vinyl substrates: due to the smooth surface of the vinyl and

96 MacPherson, p. 121
97 Allred, pp. 106-107
99 Interview with David R. Williams, Felix Schoeller Digital Imaging Inc., (October 23, 1998)
the tendency for integrated plasticisers to migrate to the film surface, the coating can partially fail to adhere, which can lead to flaking.\textsuperscript{100} This is especially problematic in warm and humid environments or in those with high climate fluctuations. If coated papers and films are considered of enough interest to the conservator, their testing for permanence will have to be continued.

5. Chemical and Biological Stability

The ability of the substances that make up an ink jet print to resist attack by chemicals is of great importance. The Image Permanence Institute in Rochester, NY, has included chemical stability in its testing of ink jet materials. However, the results are not publicly available due to the nature of the contracts with the manufacturers. Chemical stability includes long term resistance to ink ingredients that are not solvents, colorants, or vehicle, and that remain in the substrate or receptor coating, as well as to pollutants and chemicals from the environment, housing, or handling. Inks can contain impurities in the form of metallic or ionic substances that can react with the colorants. This being one of the factors that limits the shelf life of inks, it might also be a contributor to the degradation of colorants in the final print. High relative humidity and temperature would here contribute to the reaction rate.

As with many print substrates, mold growth can cause irreversible paper degradation, and could attack the colorants and the receptor coating as well. Care should be taken to avoid storing ink jet prints at a relative humidity of over 60%, as it is at this value that mold growth begins to flourish.

6. Laminates

As ink jet printing is used extensively today for indoor and outdoor advertising, the use of a laminate will greatly enhance the weatherability of a print, in that it serves as a relatively effective liquid water and pollutant barrier as well as a protection against unwanted UV radiation. Peroxides, hydrogen sulfides, sulfur dioxide, and oxygen can be kept to a large extent from coming into contact with the vulnerable colorants, which could otherwise be oxidized and corroded.\textsuperscript{101} It has been found, however, that water vapor and oxygen will diffuse through the plastic barrier in small amounts over a long period of time.\textsuperscript{102}

Its application being of an irreversible nature, lamination can only be recommended for prints that have no high monetary or artistic value or those which have a purpose that renders them of temporary value, such as being exhibited for a set period of time (as in advertising), and then becoming expendable. The overall understanding is that, though the protective coatings may enhance the durability in the short run and in extreme environments, the long term consequences cannot be completely predicted. Due to the circumstance that laminates generally employ no solvents (which liquid coatings do), they have usually not been observed to have long term adverse effects on photographic color prints. The translation of this data to the application of laminates on ink jet hardcopies remains to be evaluated.

An important aspect is the choice of plastic used in the laminate itself. If a plastic is employed that has the tendency to lead to future permanence problems such as PVC, then laminating a print with this material surely defeats the purpose of the treatment. A general problem of laminating or coating is the possibility of permanently sealing dust or dirt into intimate contact with the print. The presence of these particles could lead to localized problems over time which cannot be foreseen at the present moment. One-sided lamination or coating can be problematic in that it, in addition to causing the usual problems of sealing a surface irreversibly, allows dirt and substances access to the reverse, unlaminated side of the print which can diffuse through the substrate to form stains that are visible on the front, but inaccessible due to the plastic coating (Figure 3.6).

Should it be decided that an ink jet print be laminated, care should be taken to ensure that the print has completely dried prior to the sealing procedure. A print that feels dry to the hand is not necessarily dry enough to be sealed off from the air, and a laminated print that was not completely dry


may show ink migration problems in the long term. Experiments have shown that a minimum of eight hours, better 24 hours of drying time, to be on the safe side, are required before lamination.103

Due mainly to the general irreversible character of the lamination treatment of a print, be it with heat or with an adhesive, the preservation practice of lamination for documents was dropped in the 1970’s, and is not recommended today. The pressure applied in the heat sealing process can lead to the penetration of the paper pores by the plastic laminate, which thus has the function of a consolidant.104 The later removal of this plastic can pose a serious risk to the document. According to Kathpalia, however, experiments conducted prior to 1973 have proven that the delamination with benzene or decalyn of documents treated with a polyethylene film has been successful without any risk105 to the document.

The spray-on lacquer used in commercial photography studios and sold at photographic equipment retailers that consists of cellulose nitrate introduces all of the aging related problems associated with cellulose nitrate to the ink jet print, which include yellowing and the production of nitric acid gases. The lacquer vehicle solvents could also easily penetrate into the paper substrate or the receptor coating and there react over time with the colorants to result in fading in light and dark conditions. As can be seen from the history of lacquering color prints, the solvents penetrate the moist gelatin, causing fading and blue, cyan, red, or yellow staining.

Due to the great variety of ink receptor coatings employed with the combination of the many possible substrates, much testing may have to be conducted in the field of lamination. It might be more realistic to simply recommend that important prints not be laminated or coated until more information is available. For some applications, coating may be recommendable, such as short term prints that are made to be displayed outdoors and then discarded.

4. Preservation Concerns

*Subject: RE: MIS Archival vs. Lysonic opinions?
Date: Mon, 19 Oct 1998 18:49:31 +0800
From: Jeremy H ...
Reply-To: epson-inkjet@leben.com

Based on my experience of several months with the Iris (Lyson) inkset and 1 day with the MIS Archival, using an ESC3000. I am not sure how different the Lysonic inksets are from the Iris inksets.

Clogging
– The Iris inks caused clogging which got worse over time - they have limited shelf life
– MIS no clogging so far
– Epson inks - None

Colour gamut based on very subjective observations
– Iris inks not as good as the Epson inks mainly due to lower intensity, possibly caused by minor clogging?
– MIS almost as good as the Epson inks
– Epson - the best

Waterproofing - again only very limited subjective observations
– Iris very poor, any water causes running
– MIS very good hardly any spread of the colour even when put under a tap
– Epson - better than Iris but much worse than MIS

Lightfastness on Arches watercolour paper - based on theoretical assumptions
– Iris reasonably good
– MIS very good (pigmented)
– Epson poor* 107

The world abounds with recommendations concerning every single facet of ink jet printing, display, and longevity, but the quality of the information should always be regarded critically. As the possible combinations of printer, ink, and medium are so vast, discussions on printing options and results resemble a jungle of unchecked and subjective information, which is constantly being revised and expanded as new products enter and leave the market. It is this flexibility of products that makes the quest for reliable information difficult for the conservator, and emphasizes the necessity for serious independent testing individuals and institutions.

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103 Ibid.
104 Kathpalia, p. 128
105 Ibid., p. 130
106 Wilhelm, p. 147-148
107 Epson-Inkjet mailing list <epson-inkjet@leben.com>
In the ideal scenario, curators should only accept such prints that have detailed descriptions of the materials involved. It will be the task of the artist to deliver information on his prints. This will save the conservator much work in identification of laminates, inks, substrates etc. There is, however, no complete compilation of materials, due to the vast quantity and variation, the field is evolving very fast and rather uncontrolled, and there are no standards or guidelines. But if, in the future, a conservator is eager to find out just what the laminate on a print in a collection consists of, there will be the following choices: looking up the documented products used in the print and then referring to that manufacturer, hoping he has details on that product and if so (if it is not too old already or the information is obsolete), that he will share them, or looking up the information in a manufacturer - product - materials list, which does not exist as of yet, or doing identification analysis, which might be costly and difficult.

IRIS is today’s primary hardcopy option for fine art printing. There are, however, a great number of available ink, medium and coating combinations, the choice of which has a direct consequence on the image stability of the final product. The "Approved Preservation Practices" program for Iris fine art print producers, initiated by WIR, is designed to set standards for Giclée printing. Wilhelm writes:

"This service will not only provide extensive, copyrighted image permanence information to program participants, but will also offer ongoing consultation about new developments in the Iris fine art field. The "Approved Preservation Practices" program provides guidelines for Iris print producers concerning how to present reliable and easy-to-understand permanence information to their customers." 108

Program points include:
- Assistance of the customer in choosing ink, media, and coating, and the sharing of permanence information regarding this choice.
- Regular update of newest stability information and test data from WIR to participant.
- Prints must be marked on the back with ink / paper / coating (if any) / date / producer. This is an idea that will surely make the archivists’ and conservators’ life easier.
- Usage of the "Approved Preservation Practices" seal in advertisements and other publications. WIR insists on reviewing all publication material that concerns image stability in order to avoid the spreading of false information.
- Use of "WIR Predicted Years of Display" listings for customer education.
- Discouragement of replacement guarantees for faded prints, since factors such as storage media failure, obsolescence of hardware or software are intrinsic to digital processes and might invalidate such a guarantee. Furthermore, ink, media and coating materials might have changed, thus making an exact rendering of the original print impossible.
- The clear concept that an Iris print will not last forever, but instead has a limited lifetime.

Unfortunately, the "Approved Preservation Practices" program has been discontinued due to a lack of response among digital fine art printing studios.

Recommendations

The issues of handling, housing, storage, display, and restoration of ink jet prints have not been discussed in this investigation, since it was primarily designed as a compilation of information and schematic overview of the materials and issues connected with ink jet prints. In this sense, no recommendations are given here. Rather, it is to be hoped that the key concerns in ink jet hardcopy preservation can be singled out over time and advance toward becoming common knowledge of ink jet conservation. As ink jet prints are basically and intrinsically related to paper documents as well as photographic prints, storage recommendations and restoration treatments that have been developed in these fields might be adapted to suit the prints of the new technology. It might turn out to be of importance not only to keep up-to-date with the newest printing method, but also to have an understanding of the materiality and structure of digital prints produced over the past years.

Ink jet hardcopies can be extremely complex objects, both structurally and chemically, and the question arises as to how much knowledge of the individual nature of a print will be necessary for conservation and restoration approaches. It is improbable that the exact ingredients of an ink or receptor coating will need to be known for a restoration treatment, but a general understanding of the nature of an ink jet print would be useful. This would include questions of stability of substrate, solubility of both colorant and coating, surface susceptibility to abrasion, water- and lightfastness. Conservators will surely gain experience in the treatment of ink jet prints in the near future, and the compilation of relevant background information presented here may be extended to include concrete treatment methods. It might also turn out that restoration of ink jet hardcopies will not be an issue at all, as a new digital print can be made easily and often to a relatively low cost. One must, however, take into consideration that due to the rapid development in ink jet technology, no print made today will look exactly like a print made tomorrow. As inks become more and more light stable, the generation of hardcopies from the last ten years will become one known to be condemned to rapid fading, but it would seem that this is a phase that will eventually come to an end.

108 Wilhelm Imaging Research, Inc.
<http://www.wilhelm-research.com/index.htm>
1. Glossary

Abbreviations

C: Celcius
CIE: Commission Internationale de l’Eclairage, an organisation that has established a number of widely used color definitions
CMYK: cyan, magenta, yellow, and black, the base colors used in printing processes
DOD: drop-on-demand
DOP: developing-out paper
dpi: dots per inch
g: gram
ISO: International Standards Organization
lb: pound
lpi: lines per inch
m: meter
mL: milliliter
Mluxh: unit of light: megalux-hour
µm: micron
nm: nanometer
OD: optical density
PE: polyethylene
pL: picoliter
POP: printing-out paper
PVA: common for poly(vinyl alcohol), properly: PVAL
PVAC: poly(vinyl acetate)
PVC: poly(vinyl chloride)
RC: resin coated
RH: relative humidity
UV: ultra violet electromagnetic radiation

Definitions

Note: Definitions marked with * are quoted from Websters New Encyclopedic Dictionary, New York, 1994

absorption: the sucking up or taking up or in by one substance of another, in the case of →colorants: the taking up of energy in form of light
acuity: sharpness

adsorption: the adhesion in an extremely thin layer of molecules (as of gases, solutes, or liquids) to the surfaces of solid bodies or liquids with which they are in contact*
agglomerate: to cluster
aggregate: to cluster in a dense mass
alumina: aluminium dioxide (AlO₂)
analogue: data consisting of or systems employing continuously variable signals or data, as opposed to discreet steps or levels of →digital data
anion: negatively charged ion; →cation
apparent resolution: resolution of a →hardcopy as it appears to the naked eye of the observer
archival: a term that has been used extensively in conservation literature, but that lacks an internationally accepted definition. general understanding: with characteristics of long term stability (as in: archival quality)
auxochrome: functional group that can be either →organic or salt-forming and is attached to a molecule to modify and/or intensify the color of that substance
banding: in this context, horizontal, parallel lines in an ink jet print caused by a falsely aligned or defective →printhead
binary: relating to, being, or belonging to a system of numbers having two as its base*
bit: shortened form of the term →binary digit, the smallest unit of information that can be stored in a computer
bleed: to wick; →feather
brightness resolution: resolution relating to the number of tonal values in a →digital image
buffer: a substance capable of neutralizing acids, incorporated into many museum boards and →archival paper products
calender: to press paper between rollers in order to smooth its surface
carcinogen: a substance or agent producing or inciting cancer*
cation: positively charged ion; →anion
cellulose: a complex carbohydrate constituting the chief part of the cell walls of plants, yielding many fibrous products, and being commonly obtained from vegetable matter (as wood or cotton) as a white fibrous substance [...]*, used on a large scale for papermaking
chain scission: →scission of a polymer chain
chroma: color saturation, degree of color purity
chromophore: a specific arrangement of atoms leading to →absorption of →photons at specific wavelengths within the →spectrum of a light source

CIE L*a*b*: three-dimensional color definition model with the parameters L*: lightness, a*: range from red to green, b*: range from blue to yellow

CIE Yxy: three-dimensional color definition model representing all colors visible to the average human eye with the parameters Y: lightness, x: amount of red, y: amount of green. Usually representation is two-dimensional, excluding lightness Y

cocking: occurs as →cellulose fibers of a paper swell and shift due to →absorption of moisture, resulting in an uneven, wavy surface that often remains even after the paper has lost the excess moisture

colloid: a very finely divided substance that is scattered throughout another substance, also: a mixture consisting of such a substance together with the substance in which it is scattered*

colorant: a substance, usually a →dye or a →pigment, with the ability to absorb a certain range of wavelengths from visible light, thus reflecting only the non→absorbed wavelengths, which is perceived as color

color depth: →brightness resolution of a digital image, measured in number of →bits / pixel

colorimetry: measurement and determination of colors

conjugation: in →organic chemistry, the presence of double and triple bonds in a molecule

continuous ink jet: an ink jet system in which pressure pulses are generated directly in the →printhead by piezo crystals or heated resistors to eject drops of ink only when they are needed to print a dot

dye: a →colorant consisting of single molecules that are able to →absorb certain parts of the →spectrum of visible light and reflect others

excited state: in photochemistry, the state of a molecule after it →absorbs energy

extinction coefficient: also termed absorption coefficient, describes the amount of light of one wavelength absorbed by a molecule

feather: to wick; →bleed

gamut: the limited range of colors provided by a specific →input or →output device, or by a set of →colorants

ground state: in photochemistry, the state of a molecule before it →absorbs any energy

halftone: a method of simulating →continuous tone in →binary printing utilizing overlapping black or color process dots of varying size or position

hardcopy: →digital print on a →substrate; →softcopy

hue: color of an object as perceived by the eye

hydrolysis: a chemical process of decomposition involving splitting of a bond and addition of the elements of water*

impact printing: process of applying →ink to a →substrate utilizing physical contact between some part of the printing device and the substrate, (e.g. →offset, lithography, and flexography); →non-impact printing

ink: substance in ink jet printing (liquid or solid) which gets sprayed onto the →medium; made up of a →colorant, a →solvent, or →vehicle, and various additives

input: information fed into a →digital system

inorganic: in the context of chemistry, refers to substances that do not contain carbon atoms; →organic

ion: an atom or group of atoms that carries a positive or a negative charge as a result of having lost or gained one or more electrons; →anionic; →cationic

kogation: unique to thermal ink jet, caused by thermal decomposition of organic matter and the deposition of those products on the heat element of a thermal →printhead, thereby rendering it useless due to insulation of the heat element

Lab: abbreviation for →CIE L*a*b*

lake: a class of →pigments composed of a soluble dye →adsorbed on or combined with an →inorganic substance such as a metal

laminate: a clear coating of a variety of possible substances, usually plastic, that is applied to one or both sides of a →medium after printing for reasons of protection

lightfast: resistant to the destructive action of light
lignin: → polymer that occurs in the woody cell walls of plants and in the cementing material between them which is easily oxidized to form yellow-brown compounds and acidic products
lines per inch (lpi): measurement of output device resolution
medium: in ink jet printing, object onto which → ink gets sprayed and which carries the final image; can be made up of various layers, including the → substrate and coatings, and can be → laminated after the printing process
micelle: an → aggregation of molecules that constitutes a → colloidal particle
micron (µm): micrometer, unit of length equal to 10⁻⁶ meters
mil: unit of length equal to 10⁻³ of an inch (0.0254 mm)
molecular weight: weight of one mole (≈ 6 x 10²³ molecules) of a substance in grams
monochrome: single colored
mordant: a chemical that fixes a → dye in or on a substance by combining with the dye to form an insoluble compound*
nanometer (nm): unit of length equal to 10⁻⁹ millimeter
non-impact printing: process of applying → ink to a → substrate without utilizing physical contact between some part of the printing device and the substrate, (e.g. ink jet); → impact printing
non-polar: → polar
nozzle: in ink jet printing, the orifice in the → printhead from which → ink droplets are ejected
offset: → analog ink-based printing process, in which ink adhering to a metal plate is transferred (offset) to a blanket cylinder before being applied to the → substrate
opaque: not transmitting light; → transparent
optical density (OD): → print density
organic: in the context of chemistry, refers to substances that contain carbon atoms; → inorganic
output: information fed out of a → digital system in the form of data or → hardcopy
oxidation-reduction: a chemical reaction in which one or more electrons are transferred from one atom or molecule to another*
P: unit of measurement indicating the acidity or alkalinity of a substance on a scale of 0-14. pH<7 is acid, pH>7 is alkaline, pH=7 is neutral
phase change: an ink jet system in which pressure pulses in the → printhead eject drops of → ink that is in a heated, molten state, and which solidifies when it hits the → substrate
photo-catalysis: the chemical mechanism behind different fading characteristics depending on whether a → dye is alone or makes up a composite color
photon: a quantum (= subdivision of energy) of radiant visible energy
picoliter (pL): unit of volume equal to 10⁻¹² liter
pigment: → colorant consisting of a natural crystalline molecules or an → agglomerate of synthetic → dye molecules
pixel: in the context of ink jet printing, the smallest image forming printed dot on the → medium
plasticiser: a chemical added to substances to impart flexibility, workability, or stretchability
polar: molecule having a dipole or substance characterized by molecules having dipoles, determines solubility characteristics; → non-polar
polyethylene (PE): plastic consisting of → polymerized ethylene
polymer: a chemical compound or mixture of compounds that is formed by polymerization and consists essentially of repeating structural units
porosity: state of being able to absorb liquids due to pores
print density: or optical density (OD), of an ink jet → hardcopy is the visually perceivable and densitometrically measurable → absorption of light on the surface of a hard copy due to the presence of a → colorant. OD only measures the surface density of a dry hardcopy, not the density of the total amount of → ink that was sprayed onto the → medium.
printhead: part of a → digital printer that is directly responsible for applying → ink to a → medium
print resolution: the → resolution of a → digital print
print-through: → show-through
proof: a test print used for final color correction in the printing industry
rag: in the context of paper manufacturing, cotton rags are a source for high quality → cellulose fibers
RC paper: → resin coated paper
receptor coating: layer adhered to the surface of the → substrate that has the function of receiving and binding → ink that arrives from the → printhead nozzle
recto: front side of an object; → verso
reduction: → oxidation-reduction
refractive index: measurement of the bending (refraction) of light entering a → translucent or → transparent substance
relative humidity (RH): the ratio of the amount of water vapor actually present in the air to the greatest amount possible at the same temperature*
resin: natural → organic substances that are formed especially in plant secretions and are used in varnishes, printing → inks, and → sizing; in this context, any of a large class of synthetic products that have some of the physical properties of natural resins but are different chemically and are used chiefly as plastics*
resin coated paper: or RC paper, term used for photographic paper used in most color and some black and white printing applications, which has a polyethylene coating on each side
IV. Appendix

resolution: in the →digital context, the capability of making up a larger image out of many small and discrete entities such as pixels; a measure of the greatest amount of detail or sharpness that can be seen in an image

resonance: in photochemistry, the capability of electron vibration in a →conjugated molecule

rosin: a →translucent, amber-colored, brittle, natural →resin that is obtained from pine trees and used in paper →sizing

scission: splitting, or division of a substance or an object; →chain scission

shellac: a purified form of the →resin lac, which is secreted by an insect and which is used for varnishing

show-through: occurs when →ink penetrates the paper →substrate and is visible from the back; also termed print-through

silica: silicon dioxide (SiO₂)

sizing: a gluey substance such as a →resin, gelatin, or starch used for finishing, modifying, and filling the pores in a surface such as that of paper

softcopy: view of a file on a monitor screen; →hardcopy

solvent: a usually liquid substance capable of →dissolving or →dispersing one or more other substances*

spectrum: in this context, the full range of visible wavelengths of light energy radiation

substrate: the single or multi-layered base material of the →medium, which can have a very simple or complex structure and is a carrier for the coating, if present

surfactant: substances that enable the →dispersion or →solution of →non-polar molecules in →polar liquids or vice versa

tinctoral strength: measurement of the brilliancy of a →colorant

translucent: allowing light to pass through but →opaque instead of clear

transparent: allowing light to pass through but clear instead of →opaque

vehicle: in this context, a fluid or solid substance, depending on its physical state and on its desired function, that serves to either →dissolve or →disperse another substance or a range of substances and make them usable in a certain environment

verso: reverse side of an object; →recto

viscosity: the tendency of a liquid to flow slowly or quickly resulting from the friction of its molecules

waterfast: resistant to the destructive action of water

wettability: the ease by which a →pigment can be wet by an →ink →vehicle or a →substrate by a liquid

wick: to draw moisture by capillary action; in the context of ink jet printing: the tendency of an →ink to spread along paper fibers resulting in a loss of dot edge sharpness and overall image quality

2. Organizations and Institutions

AIC: American Institute for Conservation of Historic & Artistic Works
1717 K Street, N.W., Suite 301
Washington, DC 20006 USA
Tel: (202) 452-9545
Fax: (202) 452-9328
E-mail: InfoAIC@aol.com
URL: <http://palimpsest.stanford.edu/aic/>
Relevant subgroups: Photographic Materials, Electronic Media, Book and Paper

ANSI: American National Standards Institute
11 West 42. Street
New York, NY 10036 USA

ECPA: European Commission on Preservation and Access.
P.O. Box 19121 -1000 GC Amsterdam - The Netherlands
Tel: + 31 20 5510839
Fax: + 31 20 6204941
E-mail: ECPA@BUREAU.KNAW.NL
URL: <http://www.knaw.nl/ecpa/ecpatex/index.htm>

IAFADP: International Association of Fine Art Digital Printmakers
4220 Fair Avenue, Ste. #103
North Hollywood, CA 91602
URL: <http://www.iafadp.org/index.html>

IPI: Image Permanence Institute
Rochester Institute of Technology
70 Lomb Memorial Drive
Rochester, NY 14623-5604 USA
Tel: (716) 475-5199
Fax: (716) 475-7230
URL: <http://www.rit.edu/ipi>

FOGRA: Forschungsgesellschaft Druck e.V.
Streitfeldstraße 19
81673 München
URL: <http://www.fogra.org/>

IS&T: The Society for Imaging Science and Technology
7003 Kilworth Lane
Springfield, VA 22151 USA
Tel: (703) 642-9090
Fax: (703) 642-9094
E-mail: info@imaging.org
URL: <www.imaging.org>
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Epson Inc. Accessories & Supplies Catalog for Epson Imaging Products, vol. 10-4, Summer 1998


IRIS Graphics Inc. *Equipoise 3000 Magenta Writing Fluid, Material Safety Data Sheet, X. Stability and Reactivity*


4. Print Collection

A collection of hardcopies each made from a single digital file is being put together by the author. This collection is designed to expand and be kept up to date by the addition of new prints whenever possible. The file is available as a 300 and 600 dpi RGB TIFF document and can be converted to CMYK if necessary. It is designed to have different image areas with specific functions, all of which should help in some way or another to distinguish between different printing technologies, inks, media, and image characteristics.