Inkjet Photo Prints: Here to Stay

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Executive Summary

A recent report from the Photo Marketing Association states, "2003 was a pivotal year for the industry, with digital cameras outselling traditional cameras for the first time ever… This gap will widen in 2004[1]"… As more customers move to digital cameras, more are also choosing inkjet photo printers thanks to significant advances in image quality and convenience. The increasing numbers of customers who are using digital photography would indicate that they are very satisfied with digital cameras and inkjet photo printing and have indeed answered yes to the question: "Do inkjet photo prints have image quality equal to (or better than) traditional silver-halide photo prints?"

One question remains, however, for customers who currently use inkjet or are considering inkjet in the future to print their valuable photos: "Will inkjet photo prints last as long as traditional silver-halide photo prints?"

Estimates of the life of photo prints are based on whether the prints will be *displayed* or *stored*. In all likelihood, only a small portion of photo prints are actually displayed and subjected to regular illumination. Displayed prints are among the most treasured, and customers need to feel confident that they can enjoy these images for a lifetime. This paper will address the display permanence of inkjet photo prints including relevant results of HP internal tests and HP's current line of photo print media and inks.

Inherited Silver-Halide Permanence Standards

The science of predicting the display permanence of silver-halide photo prints is quite mature. Broadly speaking, there are two types of degradation of displayed silver-halide prints: light-induced degradation more commonly called *light fade* and thermally-induced degradation called *dark fade*. For displayed silver-halide prints, light fade is most often the limiting factor associated with the usable lifetime of the print. However, residual chemicals inherent in the silver-halide process can lead to yellowing or staining of the print paper—also considered a type of fade.

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[1]Photo Marketing Association, Photo Industry 2004: Review and Forecast, 2004: 4

The term *lightfastness* or *light fade resistance* was originally a prediction of how long a silver-halide photo could be subjected to light before noticeable fading and/or staining occurred. In laboratory tests on silver halide, light fade is accelerated by exposing the prints to elevated light intensity.

Dark fade refers to the relatively slow thermal degradation of colorants and yellowing from residual chemicals at room temperature. Standard laboratory tests accelerate dark fade by raising temperatures and creating an Arrhenius plot.[2]

Since the science of predicting display permanence was inherited from silver-halide, the inkjet industry applied a commonly-cited standard, ANSI/NAPM IT9.9 1996, to predict light fade and dark fade for inkjet photo prints. This standard suffers from several deficiencies and caveats that make credible predictions complicated—*but not impossible*. Among the issues that need to be considered carefully are lack of specific test criteria in the standard itself and its application to inkjet photo media.

The ANSI/NAPM IT9.9 1996 standard is not a specification; it only describes a set of accelerated test conditions from which to choose (such as the type of illuminant). The standard merely suggests some possible guidelines for most of the key assumptions that are necessary to predict a *numerical* value, stated in years, for lightfastness. Among these critical assumptions are the *nominal light intensity* in the customer display condition, the *type of light* illuminating the print, and the *failure criteria* that a typical viewer would associate with *noticeable fading*.

Lightfastness for Inkjet Photo Prints

In a typical accelerated lightfastness test, a diagnostic print similar to Figure 1 is subjected to high-intensity illumination for a period of weeks or months until failure criteria is reached.

Figure 1: Section of Diagnostic Print

Indoor illumination comes from a variety of sources such as incandescent bulbs, fluorescent lights, and reflected or direct sunlight via windows. For test purposes, many labs agree that the cool white fluorescent illuminant described in the ANSI/NAPM IT9.9 1996 standard is a reasonable approximation of real-world illumination conditions. However, labs are likely to differ on assumptions about light level and failure criteria. If Lab A assumes a nominal indoor room condition of 150 Lux, while Lab B assumes 450 Lux, Lab A predictions will be three times as many years as Lab B. If Lab A uses failure criteria that are less conservative than those used by Lab B, the lightfastness predictions of Lab A will be inflated as compared to those of Lab B.

The issue of non-standard test specifications for light level and failure criteria applies across all photo print technologies including silver halide, inkjet, dye diffusion thermal transfer and others. The lack of a lightfastness test specification causes confusion for customers trying to compare the lightfastness claims of different types and brands of photo prints.

[2] S. A. Arrhenius, Zeit. Fur Phys. Chem., 4, 1889:226.

Emerging De Facto Test Specifications

In the past few years, there has been a convergence within much of the inkjet imaging industry toward what might be called a de facto lightfastness test specification. Recent lightfastness claims made in ads, on packaging, or in press materials from three major inkjet print solution manufacturers—HP, Epson, and Canon—all refer to a relatively similar set of test conditions (75-degree Fahrenheit or 24-degree Celsius air and cool white fluorescent illumination) and calculation assumptions (450 Lux per 12 hour day or 500 Lux per 10 hour day). Although a de facto specification has not yet emerged for lightfastness failure criteria, HP considers the failure criteria used by Wilhelm Imaging Research, a leading test lab, to be the best that are currently available.

Lack of detailed test specifications does not mean that it is impossible to make credible lightfastness comparisons. Even the existing, non-specific standard allows for credible relative comparisons, like those available at www.wilhelm-research.com, provided one is careful to compare results derived from identical test conditions, calculation assumptions, and failure criteria.

Other Inkjet Photo Permanence Factors

While the ANSI/NAPM IT9.9 1996 standard can account for light-induced fading, there are factors other than light that may affect the permanence of a photo print. What if a displayed photo print also degrades (fades) from contact with airborne pollutants and gases? Does the thermal degradation dark-fade standard tell us anything useful about inkjet photo prints? Are there any other degradation mechanisms to worry about?

In order to understand print permanence as it relates to inkjet, it is necessary to define the two basic types of ink-receptive coating used in inkjet photo papers—*swellable* (also called non-porous) and *porous*.

The swellable type of coating was the first to be introduced. In general, swellable coatings are comprised mainly of synthetic or natural polymers that swell when contacted with water or inks. After drying, the dye colorant is encapsulated in the coating, which essentially protects the colorant from any contact with air and therefore airborne pollutants. See Figure 2.

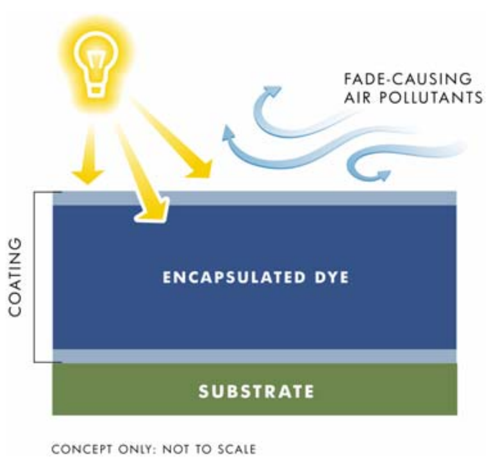

Figure 2: Swellable Coating

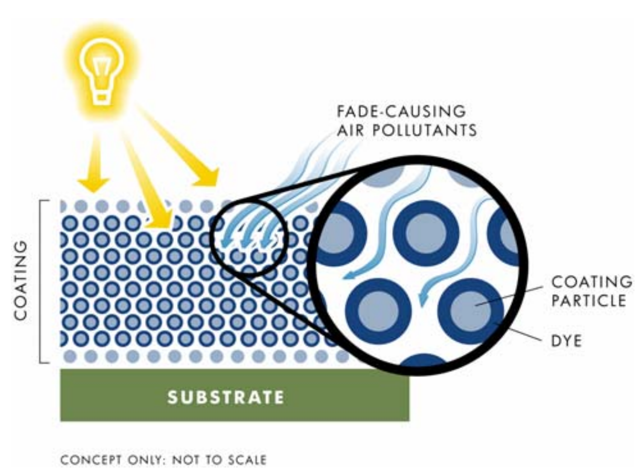

Figure 3: Porous Coating

By contrast, porous coatings for inkjet photo prints are a more recent technology that was introduced in order to decrease dry time. These semi-rigid coatings are comprised of millions of microscopic particles. The ink flows through the spaces between the particles and deposits the dye colorant on the surface of the particles as illustrated in Figure 3. Spreading the ink across the surface of all of the particles exposes it to air, which enhances dry time. (To envision how thinly the ink is spread in porous media, imagine the ink in a snapshot-sized photo spread across a tennis court.) Unfortunately, the dye deposited by the ink is very susceptible to contact with air pollutants. Thus, dye colorants on porous media are in continuous contact with air and airborne pollutants whenever the print is displayed without protection such as glass or lamination.

Air Fade Various researchers[3,4,5,6] have found that contact with airborne gases and contaminants can lead to what HP terms *air fade*. Two important points can be made about air fade:

- Air fade is not completely understood at this time. However, most research indicates that ozone is a significant contributing factor to air fade. HP research indicates that other commonly encountered pollutants may also contribute to overall air fade. An industry consensus on a predictive 'air fade' prediction (in Years) based on elevated ozone exposure tests appears increasingly likely. Even in the absence of such a standard, current methods enable a qualitative distinction between products that are highly susceptible to air fade vs. products that are relatively unsusceptible.
- HP and other researchers have consistently found that all porous media are subject to significant air fade and swellable media are much less susceptible to air fade. Figure 4 displays data gathered from an internal HP test that was presented at NIP 17.[7] HP's test was conducted on a wide variety of inkjet media that were printed with the same dye-based inks on a desktop printer. The prints were exposed to normal office air in a dark environment for a total of four months. The results shown below are the percent of optical density (OD) loss for pure cyan with an initial 0.5 OD. The failure criteria used to indicate noticeable fade was a loss of 30 percent OD.

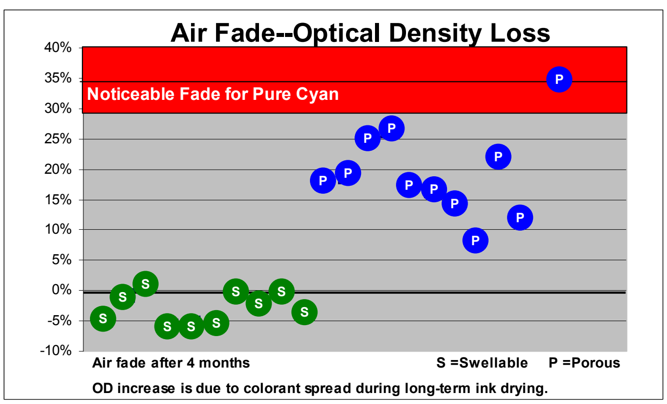

Figure 4: Air Fade Comparison

[3] M.D. Stone, PC Magazine, January 16, 2001:52.
[4] M. Oakland, D. Bugner, R. Levesque and R. Vanhanehem, Proceedings of IS&T NIP17: International Conference on Digital Printing Technologies, October 2001:175-178.
[5] D. Sid, Proceedings of IS&T NIP17: International Conference on Digital Printing Technologies, October 2001:171-174.
[6] H. Onishi, M. Hanmura, H. Kanada and T. Kaieda, Proceedings of IS&T NIP17: International Conference on Digital Printing Technologies, October 2001:192-196.
[7] S. Guo and N. Miller, "Estimating Lightfastness of Inkjet Images: Accounting for Reciprocity Failures," Proceedings of IS&T NIP17: International Conference on Digital Printing Technologies, 2001:168-191.

Figure 4 shows that lightfastness predictions based on standard accelerated methods (ANSI/NAPM IT9.9 1996) are applicable to the swellable inkjet photo print category without restriction. For the porous category, the same lightfastness prediction methods can be used, but are only applicable for predicting fade resistance for prints that are continuously protected from contact with air. Since many prints are displayed without special protective measures, manufacturers and their customers need to be cautious about lightfastness claims for any porous coating photo media.

In an article presented at the International Symposium on Photofinishing Technology titled "How Long Will They Last? An Overview of the Light-Fading Stability of Inkjet Prints and Traditional Color Photographs," [8] Henry Wilhelm compared performance of various photo prints, marking each porous media with this footnote: "Field experience has shown that, as a class of media, microporous papers used with dye-based inks can be very vulnerable to 'gas fading' when displayed unframed and/or stored exposed to the open atmosphere where even very low levels of certain air pollutants are present; to a greater or lesser degree, these papers have a pronounced sensitivity to pollutants such as ozone, and in some locations, displayed unframed prints have suffered from extremely rapid image deterioration."

HP tries to avoid misleading fade resistance claims by publishing estimates in "number of years" only on products for which the current lightfastness test standards are credible and applicable—that is, to swellable HP photo media.

Dark Fade Unlike silver-halide photos, there is no evidence that modern inkjet inks are generally subject to significant dark fade at typical indoor temperatures. Thus, the limiting factor is the yellowing rate of the ***paper*** itself, not the printed areas. Fortunately, most premium quality inkjet photo papers on the market use high-grade materials that turn yellow extremely slowly at room temperature (100 yrs. +). The only method to test for dark fade is to elevate temperature, while still remaining in the range for which the Arrhenius equation remains applicable.[9] In practice, Arrhenius constraints mean that dark fade tests for inkjet prints require one to two years before any useful predictions can be obtained. Wilhelm Imaging Research recently completed testing of prints made with HP Premium Plus Photo Paper (Glossy and Matte), printed with the HP 57 & HP 58 or HP 57, HP 58 and HP 59 inkjet print cartridges. Test results indicate that, when stored in an album or other dark place at room temperature (73°F [23°C]) and 50% relative humidity, prints should last more than 200 years before noticeable fading of the image or yellowing of the paper occurs.

Humidfastness Humidfastness refers to the migration of colorant particles when the print is exposed to elevated levels of humidity. It is the movement, not the destruction, of colorant that causes changes in color and hue that might be objectionable. HP and the inkjet industry continuously work to better understand humidfastness. The challenges include:

- Defining nominal conditions–Humidity tends to cycle up and down during the day and is strongly influenced by the season as well as the geographic location.
- Hues can change when inkjet photo prints are exposed to excessive humidity. This type of change is different than the actual color loss issues that can occur during light induced (or ozone-induced) fade. The permanence science community is making progress in defining failure criteria for humidity-induced changes, but more work is needed. HP's premium-quality papers and HP photo-capable inks are designed together with special chemistries to minimize humidity-induced changes in normal home environments. The many satisfied HP customers around the world who have used the HP six- and eight-ink color photo solutions introduced in 2002 and 2003, respectively, provide further evidence that humidity fastness is not a significant issue for HP products.

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[8] Henry Wilhelm, "How Long Will They Last? An Overview of the Light-Fading Stability of Inkjet Prints and Traditional Color Photographs," IS&T 12th International Symposium on Photofinishing Technology Proceedings book, 2002:32-37.
[9]ANSI/NAPM IT9.9 1966, Imaging Materials—Stability of Color Photographic Images—Method for Measuring.

Regardless of whether a photo print is silver halide, inkjet or some other technology, it is always a good idea to store photos in a cool, dry place. HP suggests the following guidelines:

- Avoid constant exposure to conditions wetter than 80 percent relative humidity (RH). For most homes and offices, this simply means avoiding display areas for prints that are typically high in moisture such as the bathroom.
- Fully dry prints for several days at conditions below 70 percent humidity before placing the print behind glass or in a sleeve or before laminating. For customers who live in frequently humid geographic regions and who display prints in areas without air conditioning, protecting the print from air and therefore from extreme humidity is the best approach for displaying prints.

The Role of Ink in Photo Print Permanence

All references to ink thus far in this paper have been to dye-based ink. There is another ink technology in photo printing, which uses pigmented ink. Which type of technology, pigment- or dye-based, delivers the ***best combination*** of image quality and fade resistance? Within current ink technologies available today, ***the best choice for photo printing is dye-based ink on swellable paper***.

Unlike pigmented inks, which remain on top of the paper, often forming small bumps on the surface, dye-based inks penetrate below the surface to provide rich color depth, minimal dot visibility, and uniform gloss. Dye-based prints can exhibit outstanding DOI (Distinctness of Image), a measure commonly used in the auto industry to reflect the glossiness of the painted surface or finish. DOI, an important component of *perceived* gloss, is what enables dye-based ink to produce the glossy three-dimensional "wet" look typical of high-quality photo prints. Prints made with pigmented inks often display poor DOI and undesirable variations in gloss that result from the different amounts of ink used to produce light and dark colors.

Although the lack of a true standard makes precise predictions impossible, HP internal air-fade (and ozone-fade) tests place current HP dye/swellable prints and pigment/porous prints in the 'resists air fade for decades' category, with dye/swellable showing a slight advantage in longevity. In the same tests, dye/porous products fall in the range of several months to perhaps over a year or more.

Dye molecules, by virtue of their small size, penetrate below the paper coating. Because the coating on the paper is essentially transparent, we 'see' the image even though the dye molecules have penetrated below the surface of the swellable media. This is one reason dye-based photo prints typically have better image quality on high-gloss papers than pigmented ink prints.

In addition to image quality and fade resistance, durability (scratch resistance and water resistance) is also a critical attribute. Since dye-based inks penetrate the paper's surface, dyes can deliver good scratch resistance and good water resistance on the appropriate media—the only limitation is the paper itself.

HP's Photo Print Solutions: Fade Resistance Superior to Silver Halide

Early generations of inkjet photo prints had light fade resistance in the range of three to ten years.[10] Since most silver-halide photo brands in Europe and the Americas have up to 22 years of lightfastness, early inkjet photo prints were clearly deficient. In more recent generations of inkjet photo prints, inks and media improved such that claims of greater than 25 years of "lightfastness" for branded

[10] Based on de-facto standard assumptions or Wilhelm Imaging Research assumptions, which are similar.

ink/paper/printer photo prints became possible. However, air fade greatly reduced the *net* fade performance on porous media, as some customers found to their disappointment.

HP's latest (2003 and later) photo inkjet systems push light fade resistance performance into a whole new realm —73 years or more. These systems combine HP Premium Plus Photo Paper and the latest tri-color and photo print cartridges. These HP six-ink (and eight-ink), fade-resistant systems depend on proprietary ink formulations, new dyes—many of which are exclusive to HP—and a highly evolved swellable coating that encapsulates the dye further protecting it from fade.

The benefits derived from HP's co-developed inks and photo papers are obvious in Figure 5. Photos printed using HP Premium Plus Photo Paper with the HP 57 tri-color inkjet print cartridge and HP 58 photo inkjet print cartridge exceed the fade resistance of Kodak Ektacolor Edge Generations silver-halide paper, and of Fuji Crystal Archive - the most fade resistant silver-halide paper - according to Wilhelm Research.[11] Using just the HP 57 tri-color inkjet print cartridges (introduced in 2002) with HP Premium Plus Photo Paper, for three-ink photo printing, still delivered fade resistance consistent with several silver halide brands.

For 2004, HP's newest inks accomplish two main improvements:

- **Significantly improved fade resistance for three-and four-ink configurations**
  The new inks used in the tri-color inkjet print cartridges improve lightfastness for color photos without compromising plain paper color saturation and vibrancy. Results of early internal HP testing indicate that color photos printed on HP Premium and HP Premium Plus photo papers should resist fading much longer than with previously introduced HP three- and four-ink photo printing systems.
- **Extended and improved six- and eight-ink fade resistance**
  Fade resistance tests with the newest HP inkjet print cartridges for six- and eight-ink color photo printing are in progress at Wilhelm Imaging Research. Based on internal HP test results and results to-date from Wilhelm Imaging Research, HP is confident that color photos printed with the new print cartridges on HP Premium and HP Premium Plus photo papers will resist fading longer than previous HP six-and eight-ink printing systems.

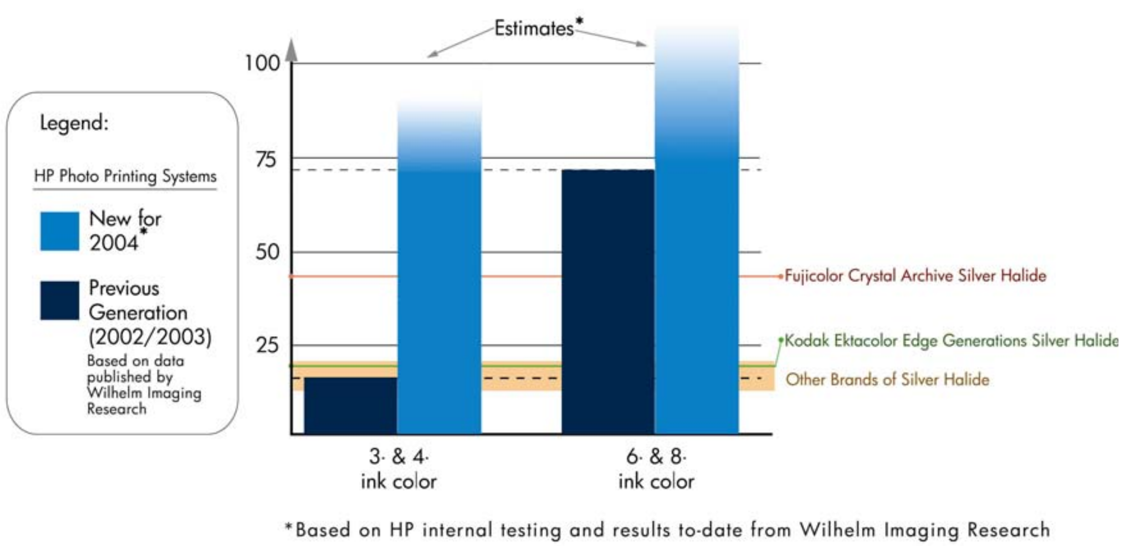

Figure 5. Fade Resistance Comparison

[11] Henry Wilhelm, op.cit.

HP currently offers fade resistance of 115 years for black and white photo prints.[12] This excellent level of performance is expected to continue with the new eight-ink printer and photo gray inkjet print cartridge that will be introduced in 2004.

Although HP swellable media offers the best fade resistance, HP porous coatings offer a useful blend of attributes such as quick dry times and scratch resistance. By offering two types of media coatings, the HP photo media product line offers customers a choice of technologies, depending on which attributes they value most. To help customers decide which HP photo paper is best suited to their particular need, HP offers a selection guide on every media package, similar to the one shown in Figure 6.

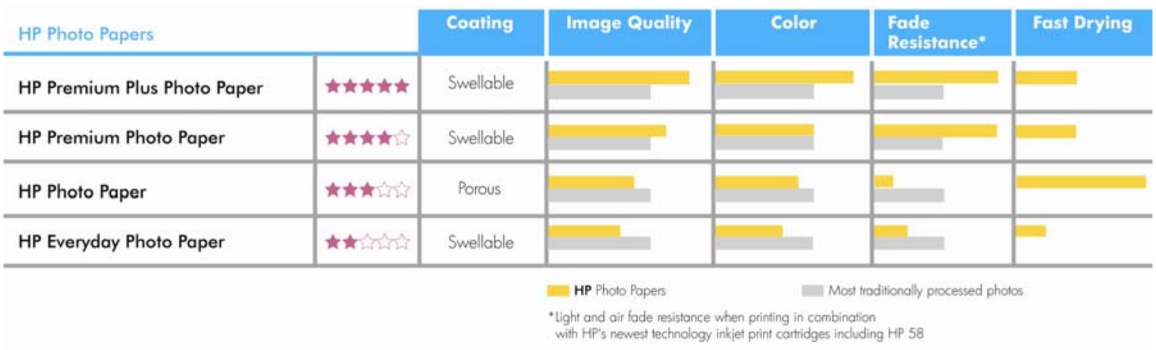

Figure 6. Media selection guide example

Summary

The science of estimating photo permanence has matured and evolved with the growing importance of inkjet photo prints. The industry appears to be moving toward a more *specific* lightfastness standard, which will benefit comparisons of all photo print technologies in the future. The industry is also reaching a sophisticated understanding about how to apply permanence tests to inkjet prints. HP's latest photo printing options provide light fade resistance clearly superior to traditional silver halide prints. Moreover, HP's inks and 'swellable' photo papers are rigorously tested for excellent resistance to degradation from airborne pollutants, humidity, and typical indoor temperatures. Thus, HP customers can display and store these prints with confidence.

Nils Miller serves as the technical liaison between HP's inkjet ink and media research and development organizations. He is a key technical leader on strategic development projects and manages HP-sponsored ink and media research programs at several universities and institutes. Miller has a B.S. in chemical engineering from Oregon State University and a Ph.D. in chemical engineering/physical chemistry from the University of Washington.

Glossary

Air fade Degradation in an inkjet image that is caused by contact with airborne gases and contaminants
Colorant Substance used for coloring a material; can be dye or pigment

[12] According to Wilhelm Imaging Research, Inc., when displayed under glass, using the HP 59 gray photo inkjet print cartridge, HP PhotoSmart 7960 printer in grayscale mode, and HP Premium Plus Photo paper.

Dark fade Thermal degradation of an image in the absence of light
Dye-based ink Ink containing dissolved colorants in molecular form less than 10 nm in size
Dye diffusion thermal transfer Technology that transfers photographic dyes from a ribbon to specially coated paper via a heat process (also called thermal dye sublimation)
Fade Destruction of the color-generating characteristics of colorants
Humidfastness Migration of colorant when a photo image is exposed to elevated levels of humidity
Inkjet Printer technology in which droplets of ink are projected onto paper
Lightfastness Prediction of how long a photo image can be subjected to light before noticeable fade occurs (also called light fade resistance)
Lux Unit of illumination equal to one lumen per square meter
Optical density (OD) Measure of transmitted or reflected light
Ozone Colorless gas that is naturally formed in the atmosphere by a photo chemical reaction; a major air pollutant in the lower atmosphere but a beneficial component of the upper atmosphere
Pigmented ink Ink containing insoluble colorant particles that range in size from 20 to 200 nm
Polymer Chemical compound consisting essentially of repeating structural units
Silver halide Photofinishing technology that uses light to expose an image onto the silver-halide crystals in photo paper; the image is developed when it comes in contact with chemicals that activate dyes that are also a part of the photo paper
Staining Image changes due to degradation of residual chemicals in silver-halide photos (also called yellowing)