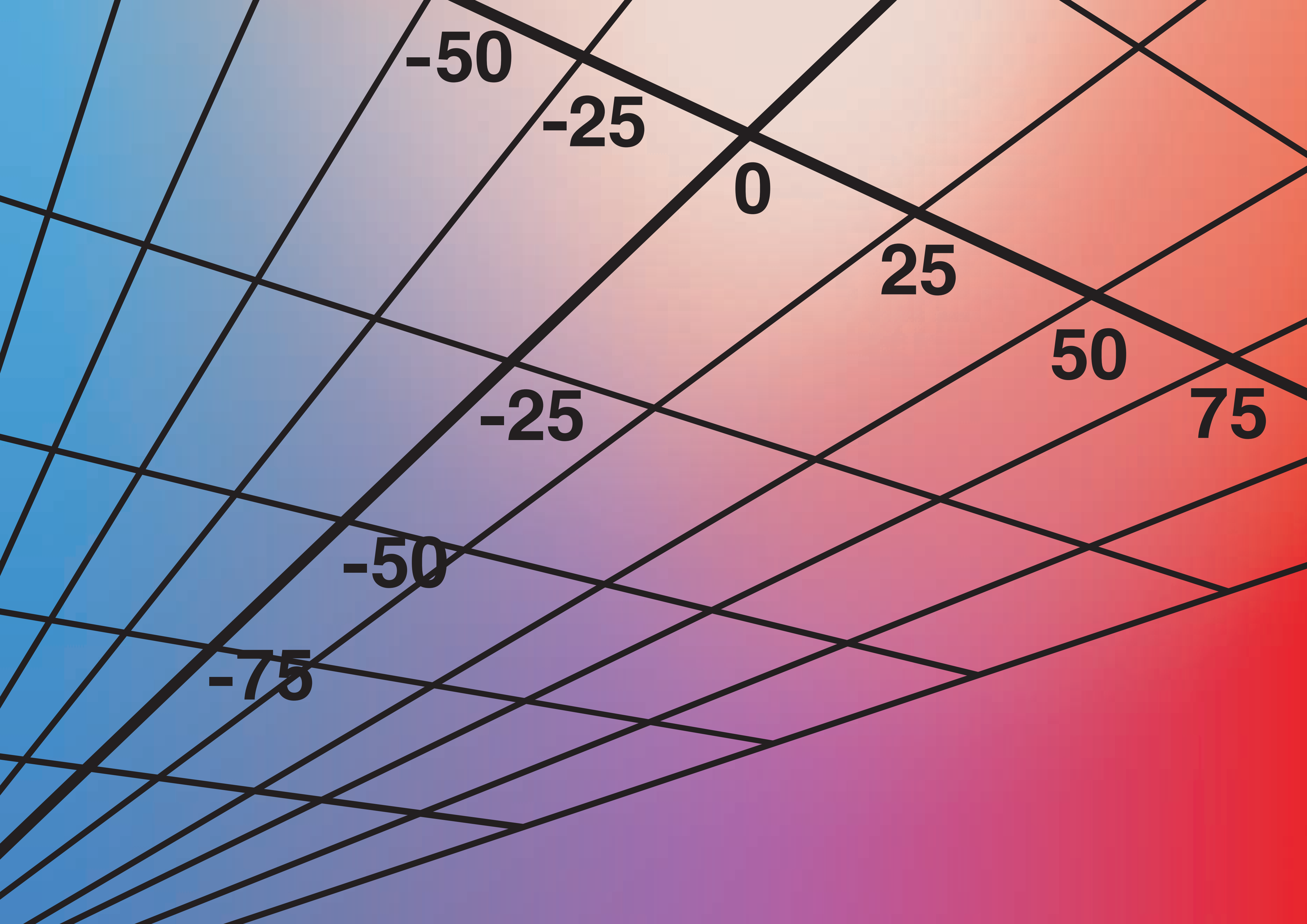
Equipment

Expert Guide
Color & Quality

HEIDELBERG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Contents

1 Light and color.

1.1 Light is color

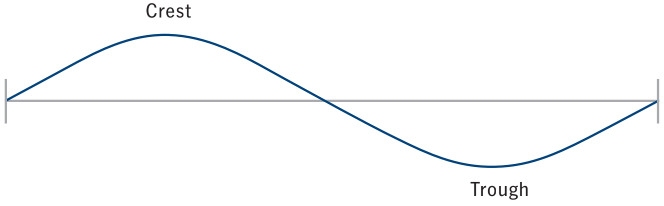
We live in a world full of color. We use colors to brighten up our surroundings to make us feel good. Interior design and color schemes have an immediate impact on our senses and the way we feel. Colors that go well together create a feeling of harmony and well-being.

The printing industry also uses color to enhance its products and to deliver ever higher quality print products to the customer.

This is leading to the creation of more and more standards for measuring print quality. If we want to assess colors, we need to “see” them. This requires light.

The sun emits light that it generates itself. In contrast, most of the objects surrounding us emit no light of their own, which is why we call them non-luminous objects. This means we can only perceive them when they are illuminated by a light source.

Light is radiation that travels very quickly – at a speed of 300,000 kilometers per second. It is made up of electromagnetic oscillations that spread out from their source in waves. Just like a wave of water, each light wave has a crest and a trough.



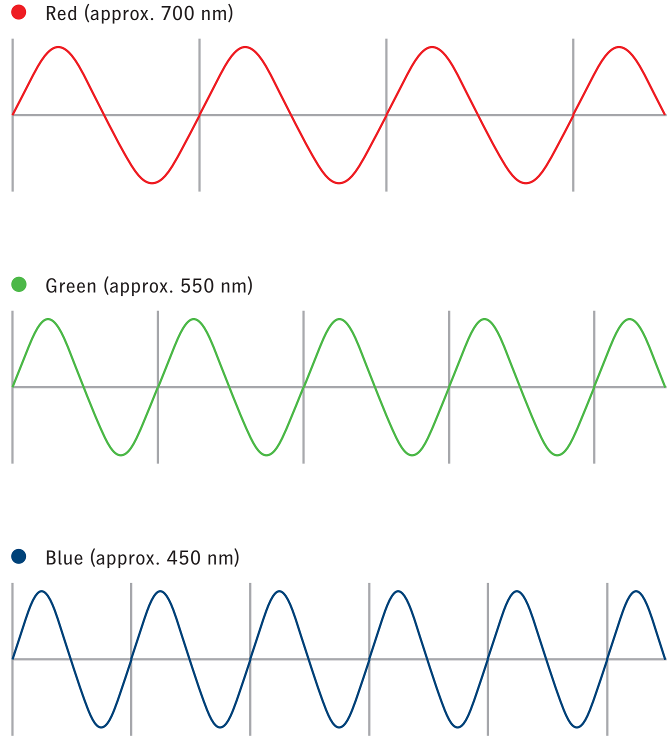
Waves can be described using either their wavelength or the number of oscillations they make per second. Wavelengths are measured in familiar units such as kilometers, meters, centimeters, millimeters or nanometers.

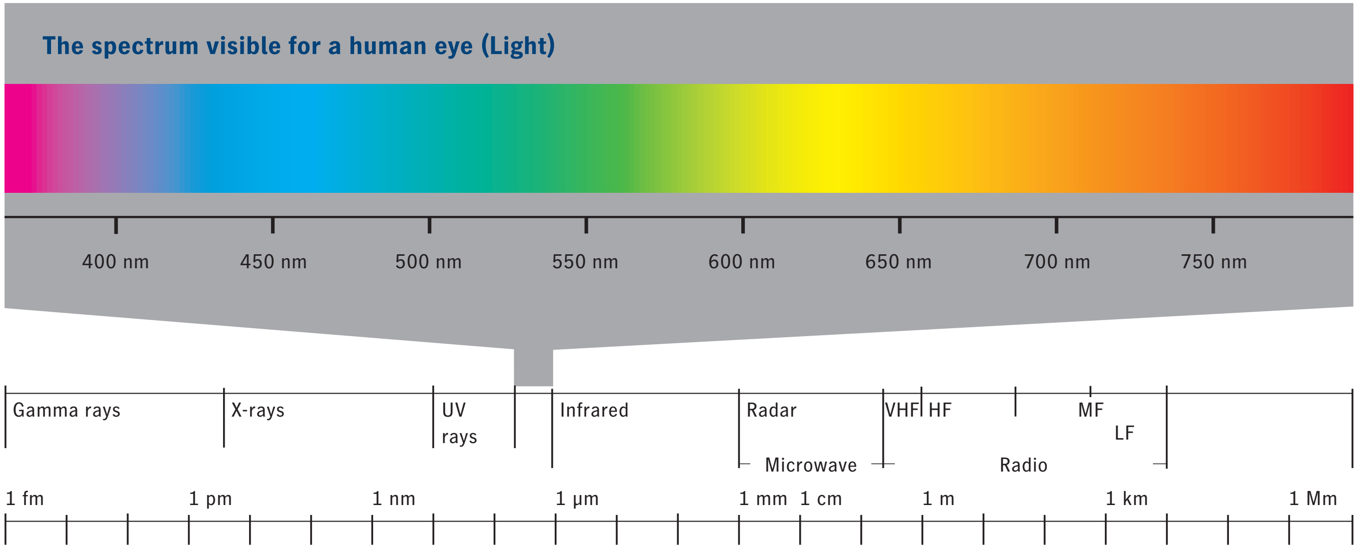
The number of oscillations per second – the frequency – is measured in Hertz.

Different wavelengths have different characteristics. X-rays, for example, are used in medical diagnostics, while many households are equipped with microwave ovens. Other wavelengths are used to transmit telephone calls or radio and television broadcasts.

Only a very small range of electromagnetic waves is actually visible to us in the form of light. The range we can see is between 380 nanometers (blue light) and 780 nanometers (red light). We can split light into its various color components using a prism. Since white light consists of a mix of colors across the entire visible spectrum, it contains all the colors of the rainbow (figure on page 6).

The figure opposite shows how wavelengths become shorter as they move from red to green and blue.





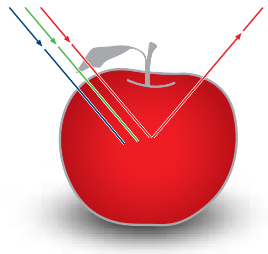
1.2 Seeing color

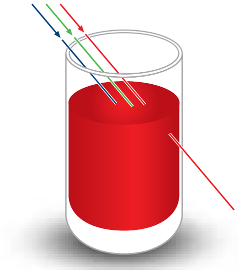
Colors only become "visible" when light falls on them – but why? Color is not a property of an object in the same way as its shape is. However, objects have the ability to absorb or reflect light of specific wavelengths. We can only perceive the colors that correspond to the reflected wavelengths. When white light strikes an object, one of the following scenarios occurs:

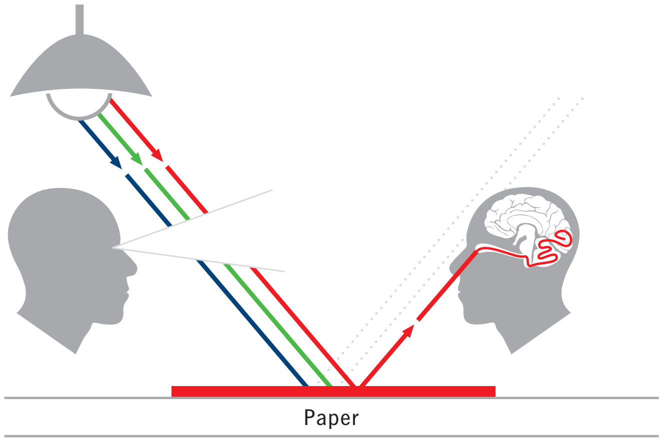
- All light is absorbed. In this case we perceive the object as being black.
- All light is reflected. In this case, the object appears white.
- All light passes through the object. In this case, the color of the light does not change. The object, e. g. glass, is entirely transparent.
- Part of the light is absorbed, the rest is reflected. We see a color, whose hue depends on which wavelengths are reflected and which are absorbed. This applies in particular to print products.
- Part of the light is absorbed and the rest is transmitted (allowed to pass through). We see a color whose hue depends on which wavelengths are absorbed and which are transmitted.
- Part of the light is reflected and the rest is transmitted. This means the color of the reflected light changes as well as the color of the light that is transmitted.

Which of these scenarios occurs depends on the properties of the illuminated object.

The light reflected or transmitted by an object is received by our eyes and converted into nerve signals that trigger the color perception in our brain.







The retina in the human eye contains light-sensitive cells. There are two types of cells – rods and cones. The rods distinguish between light and dark, while the cones respond to different colors. There are three different types of cones and each one is sensitive to a different wavelength range. Some react to light in a range of around 400 – 500 nanometers and are, therefore, sensitive to blue. Others "see" only in the green range, while the third type is primarily sensitive to red light.

This structure with its different cones makes the human eye so sensitive that we can perceive and distinguish between several million different colors.

1.3 Color mixing

1.3.1 Additive color mixing

In additive color synthesis, the light of different colors is superimposed. The color white results when all the colors of the spectrum are superimposed.

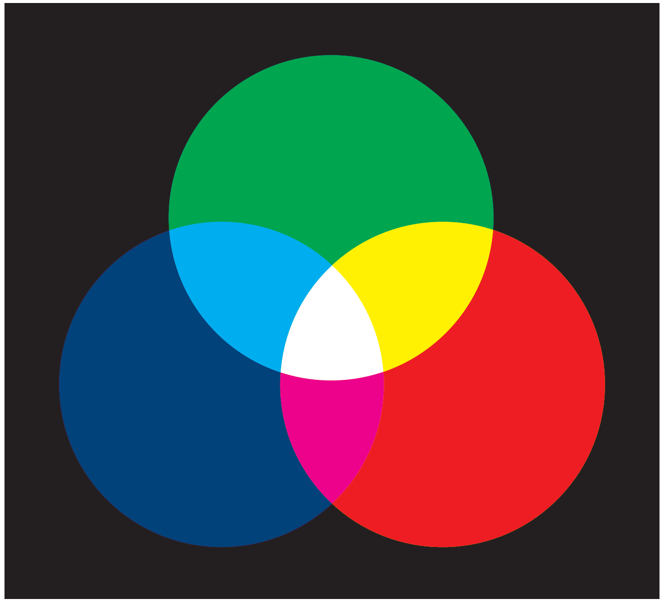
The additive primary colors are red, green and blue. Each of these colors represents one-third of the visible spectrum.

The principle of additive color synthesis can be clearly illustrated using three slide projectors. Each projector generates a circle of light on a screen in one of the three additive primary colors.

The principle of additive color synthesis is used in color televisions.

Additive mixed colors

Green	+	Red			= Yellow
Green	+	Blau			= Cyan
Blue	+	Red			= Magenta
Blue	+	Red	+	Green	= White
No light					= Black



The following mixed colors can be seen where the three circles of light overlap.

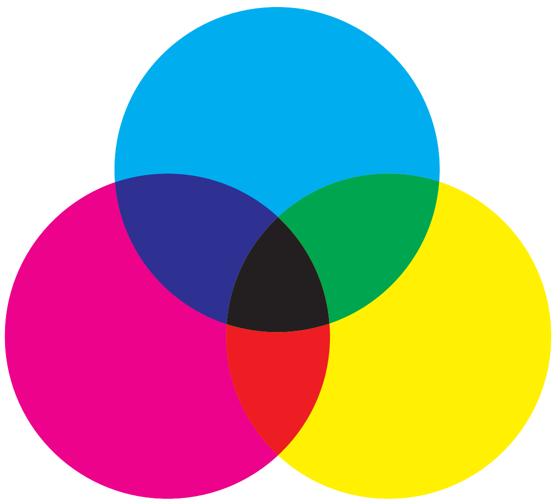
1.3.2 Subtractive color mixing

Subtractive color synthesis removes different color components from white light. Removing all the color components results in black.

The subtractive primary colors are cyan, magenta and yellow. Each of these colors represents two thirds of the visible spectrum.

Subtractive mixed colors

Cyan	+	Yellow			= Green
Yellow	+	Magenta			= Red
Magenta	+	Cyan			= Blue
Cyan	+	Magenta	+	Yellow	= Black
No color					= White



In subtractive color mixing, overprinting cyan, magenta and yellow results in the following mixed colors.

They can be produced by removing one additive primary color from white light (e. g. with a filter) or by superimposing two additive primary colors.

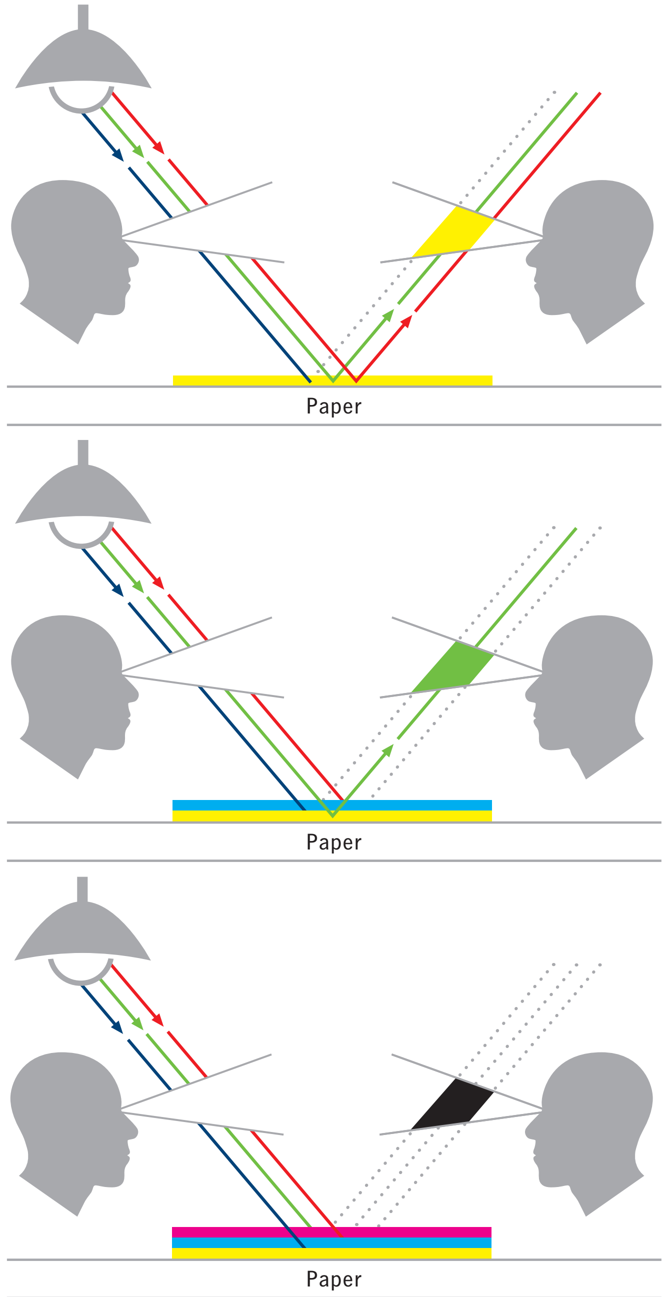
Printing inks are translucent (transparent) substances that act as color filters. So which color do we see if we print a substance that absorbs blue on white paper?

Blue is removed from the white light and the other components (green and red) are reflected. The additive superimposition of these two colors results in yellow. This is the color we actually perceive.

In this case, the printing ink has subtracted one-third (blue) from the three colors in white light (red, green, blue).

As another example, two transparent substances are overprinted – for instance yellow and cyan printing ink. These two substances first filter the blue component from the white light and then the red component, and we perceive the resulting color as green. The two inks have subtracted two thirds of the color components from the white light.

If cyan, magenta and yellow are overprinted, all incident light is absorbed (i.e. there is no reflection). We perceive black.



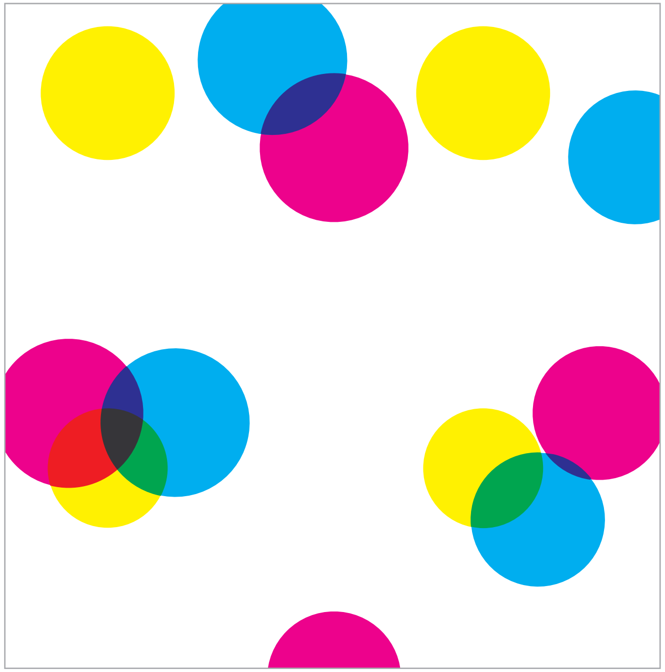
1.3.3 Autotypical color mixing

Color images are printed with cyan, magenta, yellow and black inks. The black ink enhances the contrast and the depth effect in the image.

The black produced by subtractively mixing cyan, magenta and yellow is never really a deep black due to the pigments used in the chromatic inks.

In conventional Offset printing, the size of the halftone dots depends on the desired hue (see Section 2.2). When overprinted, some of the dots of the individual colors are adjacent to one another, while others partially or entirely overlap. If we look at the dots through a magnifying glass (see figure), we perceive colors which, with the exception of paper white, are the result of subtractive color synthesis. However, without a magnifying glass and from a normal viewing distance, the human eye can no longer discern the individual dots in the printed image. In this case, the printed colors are an additive mixture of colors.

Combining additive and subtractive color synthesis is called autotypical color synthesis.



1.4 Color systems

Everyone perceives colors differently. If several people were to describe a hue, their descriptions would widely diverge. Press operators, however, need uniform evaluation standards to define the colors they work with, which has led to the creation of various evaluation systems. A number of ink manufacturers produce sample books and give the colors designations such as Saphira® C 100.

Others use color swatches such as HKS and Pantone. Another useful tool is the color wheel, which can consist of 6, 12, 24 or even more segments.

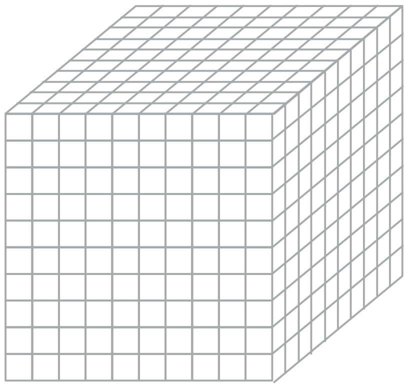
All these systems use color samples to show the individual hues and assign names to them. They are, however, never all-encompassing and are rarely suitable for making calculations.

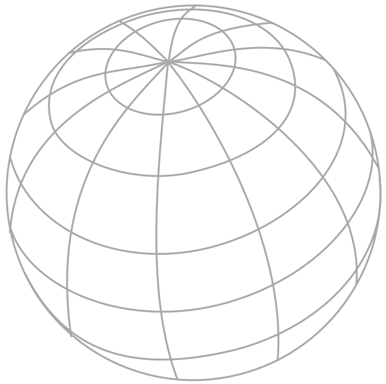
As we have seen, the way we perceive color depends on how the red, green and blue-sensitive receptors in our eyes are stimulated. Three numerical values are therefore required to unambiguously describe all possible colors.

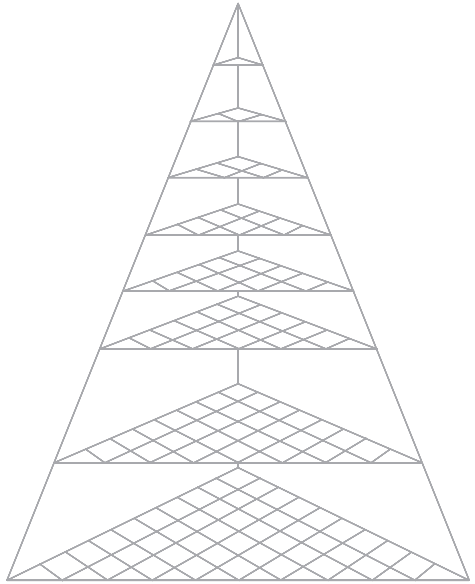
Using such a system, we would describe green,
for example, as follows:
Green = 0 × Red + 1 × Green + 0 × Blue,
or even shorter:
$G = 0 \times R + 1 \times G + 0 \times B$.

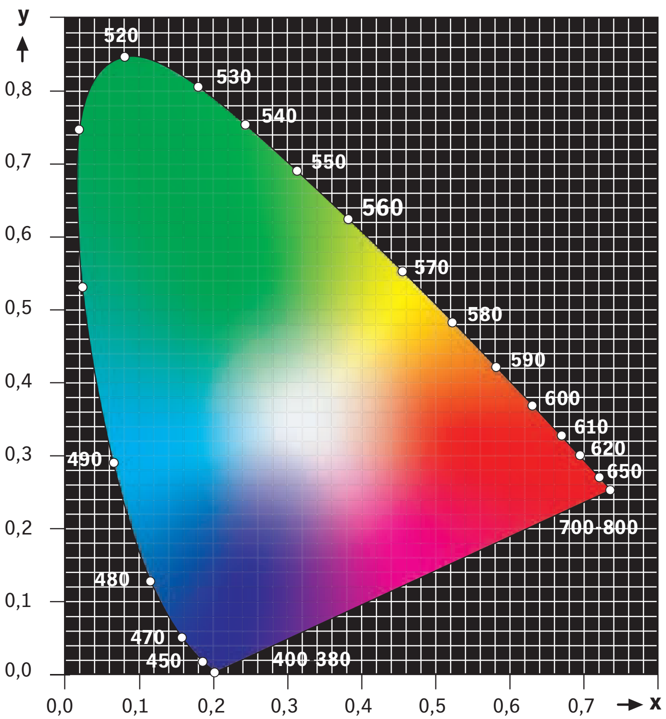
If we imagine and plot the primary colors as the axes of a system of coordinates, the result is a so-called color space.

Many experts have studied color systems and developed all kinds of ideas as to how a color space should be structured, but there are advantages and disadvantages to all of these color spaces.









Visually perceivable colors on a luminance plane in the CIE color space (CIE chromaticity diagram).

The most important color spaces are standardized internationally. They are used in a wide variety of production applications, e. g. the ink and coatings industry, textile manufacturing, and the food and pharmaceutical industries. In the printing industry, the XYZ and CIELab color systems are now widespread. (The acronym CIE stands for "Commission Internationale de l'Eclairage" = International Commission on Illumination).

The XYZ color system uses the designations X, Y and Z for the color components instead of R, G and B. For practical reasons, these are used to arrive at color value components x and y and the luminance reference value Y (the luminance reference value indicates the brightness of non-luminous colors). A color's location in the color space can be defined precisely using these three color coordinates.

This system is also often depicted as a two-dimensional figure that resembles the sole of a shoe. The x-axis of the coordinate system represents the red components of a color, the y-axis the green components. In this way, each color can be assigned to a specific point within the coordinate system. However, this diagram does not take brightness into account.

One problem with this system is the fact that the measurable distances between the individual colors do not correspond to the differences in color we perceive. For example, if you look at the figure on the left, you will see that a difference between green and yellow-green only becomes visible after some distance, while there is only a very small distance between blue and red.

2 Color in Print.

Quality assurance in printing focuses on ensuring correct and consistent color reproduction over the entire print run. In addition to the inks and the color of the substrate, the key influencing factors are the ink film thickness, halftone values, color balance, ink acceptance and printing sequence.

2.1 Ink film thickness

In offset printing, technical constraints limit the maximum ink film thickness to approx. 3.5 micrometers.

If art paper is used together with process colors according to ISO 2846-1, the correct color coordinates should be achieved with ink film thicknesses between 0.7 and 1.1 micrometers. If unsuitable color separations, substrates or inks are used, the standardized corner points of the CIE chromaticity diagram may not be achieved.

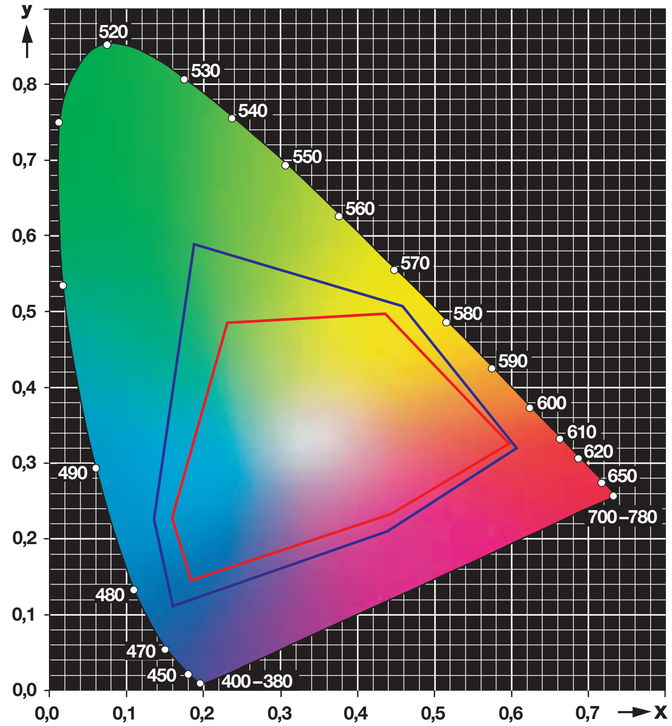
The reproducible color gamut is also reduced if saturation is not optimal. In the figure opposite, the red-edged area shows a color gamut that has been reduced as a result of underinking all three process colors. The blue-edged area could be achieved if saturation were optimal.

From a physics viewpoint, the influence of the ink film thickness on the visual appearance can be explained as follows:

Printing inks are translucent rather than opaque. Light penetrates the ink. When passing through the ink, it strikes pigments that absorb a greater or lesser part of certain wavelengths.

Depending on the pigment concentration and ink film thickness, the light strikes a larger or smaller number of pigments; this causes different amounts of light to be absorbed. The rays of light finally reach the surface of the substrate and are reflected by it. This means the light must pass through the ink film again before it reaches the eye.

A thick layer of ink absorbs more light components and reflects fewer than a thin layer; the observer, therefore, sees a darker and more saturated hue. The light component arriving at the viewer's eye, therefore, is the basis for assessing each color.



2.2 Tonal value

The halftone value is the most important factor, other than the ink, when it comes to the visual appearance of the shade of a color. In films or digital image files, the halftone value is the proportion of a specific area that is covered by halftone dots. The lighter the color to be reproduced, the smaller the proportion of the area that is covered. To reproduce different color shades, conventional screening with constant screen ruling (aka screen frequency) uses halftone dots whose size depends on the tonal value required.

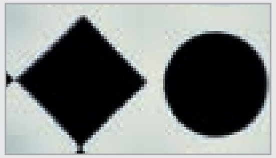
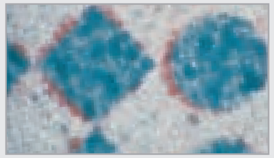
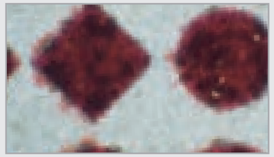
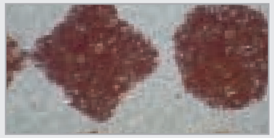
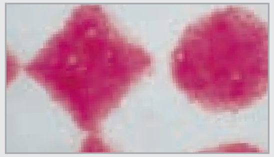
In contrast, in frequency-modulated screening, the halftone dots are identical in size but the distances between them vary. Halftone values are usually specified as a percentage.

2.2.1 Changes in tonal value

When a halftone dot is transferred from film to the plate, blanket and finally the substrate, the geometric dot size, and hence the halftone value, may change as a result of various factors.

The process-related changes in tonal value (see Section 2.2.3) can be compensated for at the prepress stage.

It is impossible to predict whether or how halftone values are affected by printing problems. That is why particular attention must be paid to them during the printing process. These are the most frequent printing-related problems with halftone dots:

The journey of a halftone dot	Factors influencing halftone dots	Appearance of halftone dots
Film Assembly Camerawork	Film edges, adhesives	 Two halftone dots on film (magnified approx. 150 times)
Development	Chemicals, development times	
Printing plate	Materials, wear during printing	 Halftone dots on the plate
Platemaking	Exposure time, vacuum, undercutting	
Dampening	Amount of dampening solution, pH value, Surface tension, water hardness, temperature	 Halftone dots on the plate after inking
Inking	Ink film thickness, consistency, temperature	
Blanket	Material, condition, surface	 Halftone dots on the blanket
Printing Blanket/substrate	Cylinder rolling	
Substrate	Surface, paper grade	 The high magnification clearly shows the excellent result on the substrate
Sheet transport	Transfer register	
Delivery	Smearing	

Dot gain/dot loss

Dot gain. When halftone dots grow in size relative to the film or digital image, this is called “dot gain” or “tonal value increase” (TVI). This can be caused in part by the printing process, materials or equipment – factors that are relatively difficult for the press operator to influence. It can also be caused by the inking, which the operator can control.

Fill-in. Fill-in is the result of non-printed areas in the shadows being reduced or even disappearing completely. Sometimes this can also be caused by slurring and doubling.

Dot loss. Dot loss is the decrease in dot size during the printing process in comparison to the film or digital image. In practice, the term “dot loss” is also frequently taken to mean a decrease in dot gain, even though the print still exhibits dot gain compared to the film or digital image.

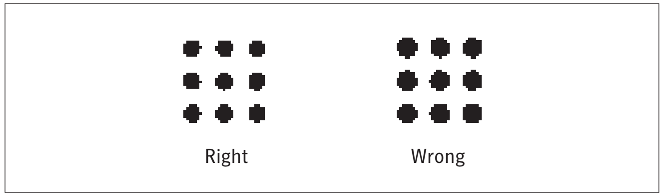
Dot deformation

Slurring. In slurring, the shape of the halftone dot changes during the print process when the printing plate and blanket and/or the blanket and the print sheet move in relation to each other, e.g. a circular dot becomes oval. Slurring in the print direction is known as circumferential slurring, while slurring at right angles to this direction is called lateral slurring. If both types of slurring occur at the same time, the direction of slurring is diagonal.

Doubling. In offset printing, doubling occurs when a second, usually smaller sized, shadowy ink dot is unintentionally printed next to the intended dot. It is caused when ink is transferred back onto the next blanket, but out of register.

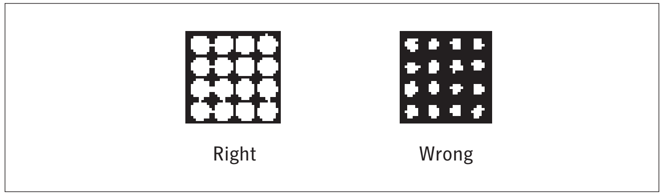
What the press operator needs to watch

Dot gain can be measured and visually assessed by means of print control strips. Print control strips are particularly useful for a purely visual assessment. Fill-in can be easily monitored using screen measuring elements with high tonal values.

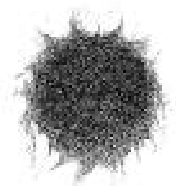


Dot gain

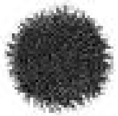
Dot gain and fill-in are generally the result of excessive inking, insufficient dampening solution, too much pressure between the plate and the blanket or a blanket that is too slack. Sometimes they can also be due to an incorrect adjustment of the inking and dampening form rollers.



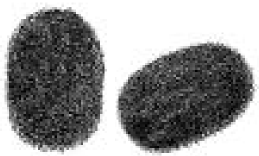
Fill-in



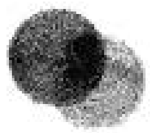
Dot gain



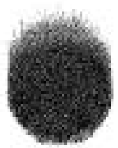
Dot loss



Slurring

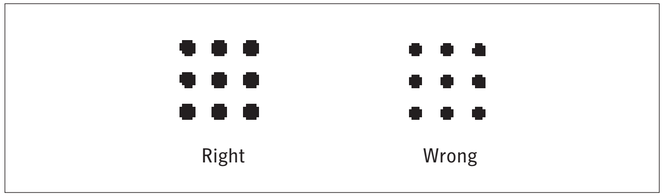


Doubling



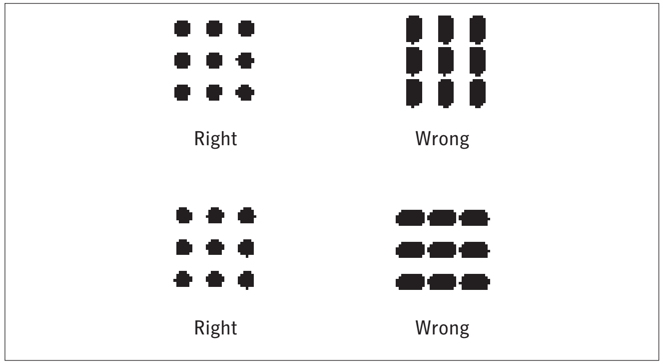
Smearing

Even under normal conditions and when the plate has been correctly copied, tonal values in the print always increase to a certain extent in comparison to the original film or digital data. Dot loss can occur under abnormal conditions such as when the plate runs blind or ink builds up on the blanket. To avoid these problems, the press operator should wash blankets and inking units more frequently, possibly change the ink and the color sequence, as well as check the form rollers, printing pressure and cylinder rolling.



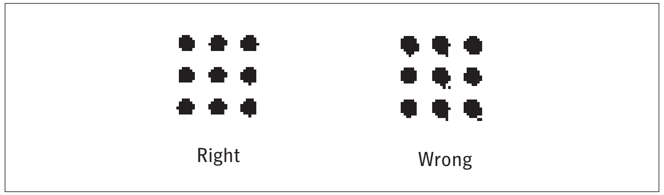
Fill-in

Slurring is most apparent in line screening. In many cases, the parallel lines provide information on the slurring direction. Circumferential slurring usually indicates a difference in rolling between the plate cylinder and the blanket cylinder, or that the cylinders are pressing too hard against each other. That is why the cylinder rolling and the printing pressure should be monitored very closely. In many cases, the blanket may not be tight enough or too much ink has been applied. Lateral slurring rarely occurs on its own. If it does occur, the substrate and blanket should be examined very carefully.



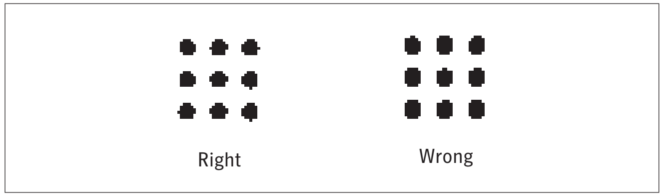
Slurring

The same elements are used for monitoring both doubling and slurring. A magnifying glass should also be used to inspect the halftone dots, because line screening control elements on their own cannot reveal whether doubling or slurring has occurred. There are many causes of doubling, but they generally are to do with the substrate or its immediate environment.



Doubling

Smearing occurs very rarely on modern sheetfed presses. When it does, the most likely sources are the areas of a sheetfed press where the sheet is supported mechanically on the freshly printed side. The risk of smearing is higher if the substrate is stiff. Smearing can also occur in the delivery pile and on perfecting presses.



Smearing

The type of change in the halftone value can be rapidly established by means of visual control elements such as the SLUR strip that are printed at the same time. These control elements visually emphasize the printing problem.

Errors such as dot gain, dot loss, slurring or doubling are more pronounced in fine screens than in coarse ones. This is because fine halftone dots increase or decrease by the same amount as coarse ones. However, many small dots together have a total circumference several times greater than that of coarse dots with the same tonal value. This means that during printing, more ink is applied around fine screen dots relative to coarse ones. That is why finely screened areas appear darker. Control and measurement elements make use of this fact.

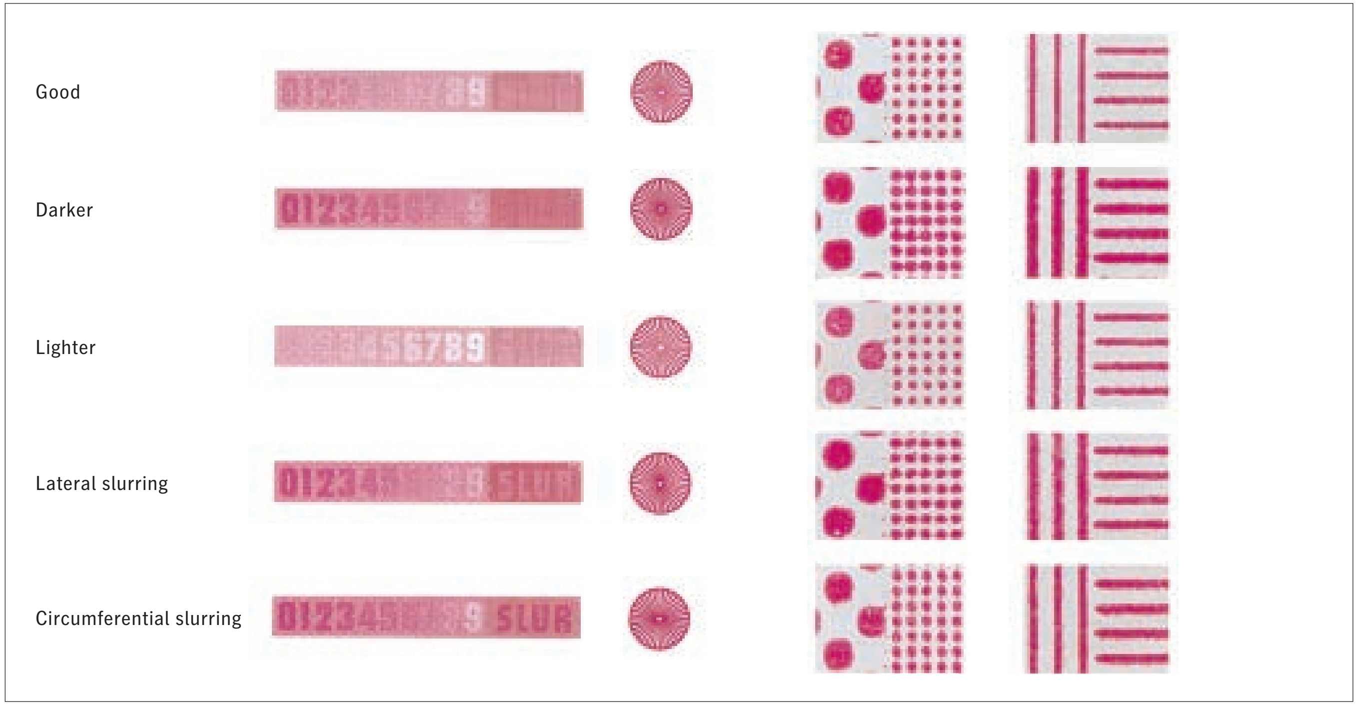
SLUR strip

As an example, let us look briefly at how the SLUR strip is made up and how it works (see figure on this page). This strip combines coarse halftone elements (background) and fine halftone elements (numerals).

While the coarse halftone background has a uniform tonal value, the numbers 0 to 9 have a fine screen ruling and an increasingly lighter tonal value. On a well-printed sheet, you can no longer see the number 3 as it and the coarse halftone background have the same tonal value. If the screens experience dot gain during printing, the next-highest number with the lighter tonal value approaches the tonal value of the background. The darker you print, the higher the value of the invisible number.

This works in reverse when dot loss occurs. In this case, you can no longer see the numbers 2, 1 or even 0 as you would in a good print. However, since these numbers merely indicate that the print is becoming darker or lighter, the causes need to be ascertained by examining the plate or print with a magnifying glass.

The part of the SLUR strip to the right of the numbers mainly shows whether slurring or doubling has occurred. The readability of the word SLUR is no better in a lighter or darker print than in a good print; the entire patch appears merely slightly lighter or darker.



SLUR strip

It is easy to detect the directional spread typical of slurring and doubling in the word SLUR. In the case of circumferential slurring, for example, the horizontal lines forming the word SLUR, which run parallel to the sheet's leading edge, become thicker. If lateral slurring has occurred, the vertical lines forming the background of the word SLUR appear darker.

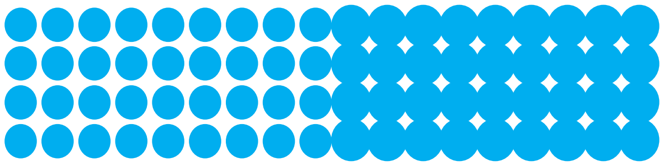
The figure above illustrates how changes in the halftone dots affect printing, using dot gain as an example. If the dots of even just one color are larger than they should be, the result is a new hue – which naturally also has an effect on the overall appearance of the printed image.

In offset printing, the image transfer from plate to blanket to substrate usually results in a certain amount of dot gain. Control strips can tell you whether the print result is good or bad, but they cannot provide absolute figures or indicate the exact nature of the problem. That is why an objective measurement method is required to assess the quality of the halftone values with quantifiable figures.

2.2.2 Dot gain

Dot gain (or TVI) is the difference between the tonal values of a screened film or digital image and the tonal values of the print. The following refers only to data, although the same applies to both film and data. Differences can result from geometric changes in the screen dots or the phenomenon known as light trap (see Section 3.4.4).

Dot gain, like tonal value, is specified as a percentage (the calculation formulae are set out in Section 3.5). Since dot gain can vary in different tonal areas, when we specify dot gain values we also need to state in which tonal area.



Right Wrong

Example: 13 % dot gain in the 40 % tonal area. Modern measurement devices show the actual dot gain in different areas.

Please note: The dot gain Z indicates the difference between the halftone value in the print FD and the halftone value in the film copy FF or in the digital data in absolute figures. The above example results in a 53 % tonal value in print, whereas the data/film has 40 %.

2.2.3 Characteristic curve

The deviation of the halftone value in the print from the halftone value in the data can be clearly described in the "print characteristics" or "characteristic curve", which can be directly used to optimize reproduction quality.

To determine the characteristic curve, graduated halftone patches and a solid patch with all colors are printed under repeatable conditions. The halftone and solid patches are then measured with a densitometer or spectrophotometer. When the resulting values are plotted in a diagram against the relevant values in the original data, the result is the characteristic curve.

This curve is only valid for the specific combination of printing ink, paper, printing pressure, blanket and printing plate for which it was originally calculated. If the same job is printed on another press, using different ink or paper, the characteristic curve may be different.

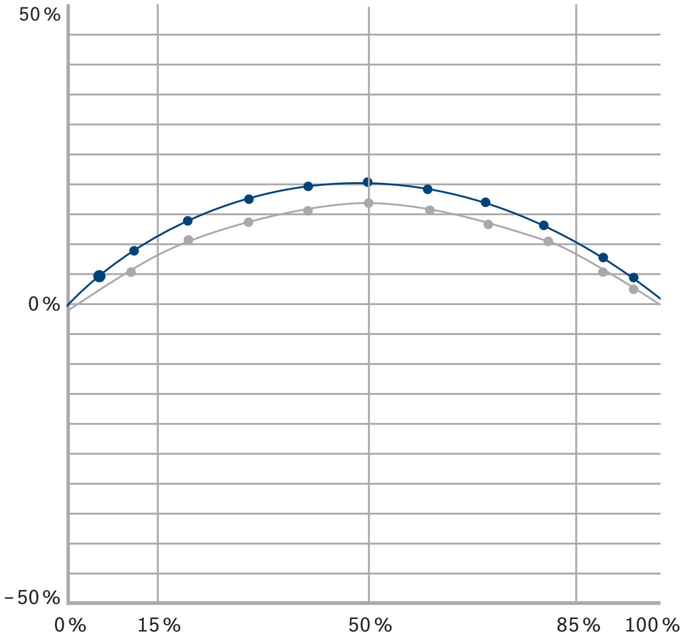
The figure on page 18 shows characteristic curve 1 at an angle of 45 degrees. This curve is not normally attainable; it represents the ideal state in which the print and data deliver identical measurements. Characteristic curve 2 shows the halftone values actually measured in the print. The area between the two lines is the dot gain.

The mid-tones deliver the most meaningful figures for determining the dot gain in the print. The characteristic curve shows that this is where the tonal value deviations are most pronounced. Using characteristic curve 2, the CTP system or filmsetter can be set up so that the required tonal values are achieved in the print (with the usual dot gain).

It is important to ensure in advance that the imagesetter is set up so that the dot size on the plate corresponds exactly to the dot size in the data. This also applies to filmsetters. In other words, a tonal value of 50 % in the data file must also result in 50 % on the plate (film). This first step is known as linearization. In the second step, the dot size is adjusted based on the test print. This is known as process calibration. In basic RIPs, linearization and process calibration are combined in a single curve. This means that any change to the linearization (e. g. resulting from new plates) also affects the process calibration and vice versa.

The Prinect® workflow keeps both these calibrations clearly separate from each other. If conventional plate copy and CTP are used side by side, it is only possible to adapt the CTP to the results of the conventional plate copy. If plate copy is replaced by CTP, it is essential that a process calibration be performed. Plates that are imaged linearly will always change the print result. This is because changes to the dots in the plate copy are no longer an issue (lighter dots in positive copy, darker dots in negative copy).

The figure opposite shows the deviation in dot gain between the required tonal value (here ISO-12647-2, gray) and the actual print result (blue).



Tonal value deviation between target (gray) and actual value (blue)

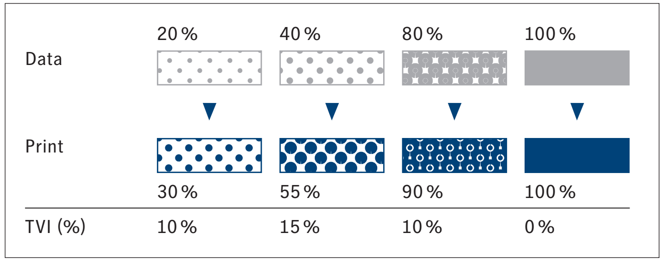
The Calibration Manager in Prinect® MetaDimension® depicts all tonal values in a clear overview. The difference between the target and the actual values is used to calculate the dot size required on the plate.

Nominal	=	tonal values in the digital data
Process	=	required target values in the print (here: ISO 12647-2)
Measurement	=	actual values in the print
Calibration	=	corrected tonal values on the plate

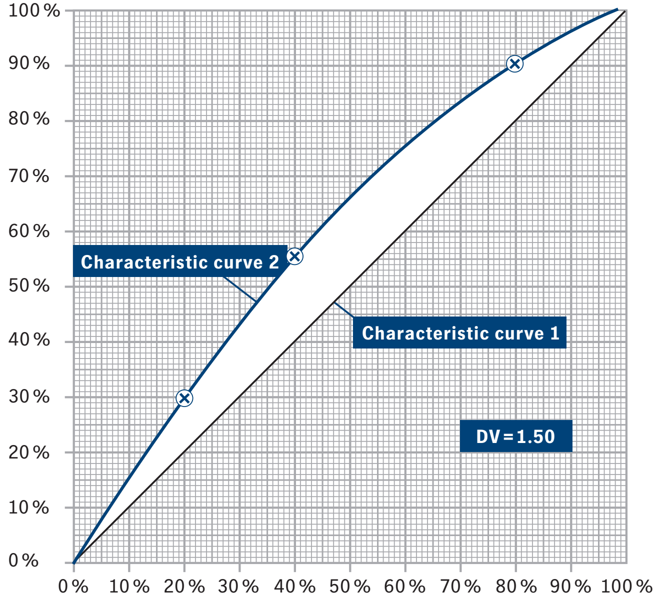
Nominal %	Prozess %	Measurment %	Calibr. %
0.0	0,0	0,0	0,0
5.0	8,21	9,99	4,05
10.0	16,1	18,18	8,62
20.0	30,5	31,89	18,93
30.0	43,5	43,95	29,62
40.0	55,3	55,44	39,87
50.0	66,0	65,48	50,54
60.0	75,6	74,61	61,17
70.0	84,0	82,55	71,94
80.0	91,0	89,69	82,02
90.0	96,5	95,77	91,35
95.0	98,44	98,2	95,58
100.0	100,0	100,0	100,0

Tonal values in Calibration Manager.

Minor deviations always occur in practice due to process fluctuations. For this reason, tolerances are specified for dot gain. To maintain the print quality as consistent as possible, it is vital to constantly monitor the tonal values using a print control strip and Mini Spots® from Heidelberg.



Dot gain



The depicted characteristic curve is the result of the above dot gain values.
Characteristic curve 1: tonal value in the digital data

2.3 Relative print contrast

As an alternative to dot gain, you can also calculate the relative print contrast Crel. (%); this is particularly useful for monitoring the three-quarter tones.

A print should have as much contrast as possible. To achieve this, the solids need to have a high ink density and the screen must be as open as possible (optimal tonal value difference). Increasing the ink volume results in a greater density of the halftone dots, which enhances the contrast. However, this process is only worthwhile up to a certain limit, after which the dots become fuller and – particularly in the shadow areas – join up with each other. This reduces the proportion of paper white and the contrast lessens again.

If none of the available measuring devices is able show the contrast value directly, the relative print contrast can be determined through calculation or using the corresponding FOGRA chart. (The calculation formulae can be found in

Section 3.5.3). Should the contrast worsen during the print run, despite consistent solid density, this may be a sign the blankets need washing. If the solid density is correct, the contrast value can be used to assess various factors that might influence the print result, for example:

- Cylinder rolling and printing pressure
- Blankets and packing sheets
- Dampening
- Printing inks and additives

The relative print contrast is no longer stated in the ISO 12647-2 standard. Instead, values are given for the solid tone colors and the dot gain in the individual colors. On the basis of these values, the relative print contrast can then be determined accordingly. However, if you deviate from this standard, for example by using an FM screen, the relative print contrast still remains an important variable.

2.4 Color balance/Image composition

As mentioned earlier, hues in four-color printing are reproduced using specific proportions of cyan, magenta, yellow and black. Changes in these components result in deviations in color. To prevent this from happening, the color components must be maintained in the balance needed for the required hue.

If only the black component changes, the hue merely becomes lighter or darker, which the observer will not find particularly irritating. This is also the case if all chromatic colors change by the same amount in the same direction. We react much more critically when the hue itself changes. This happens when the color components change by different amounts, and especially when the individual chromatic colors change in opposite directions. These types of changes in color balance are easiest to detect in gray patches, which is why we often talk about gray balance

Image composition principles

How much impact the unavoidable fluctuations in the individual inks have on the print process depends first and foremost on the image composition principles defined in prepress. Relevant questions for printing are:

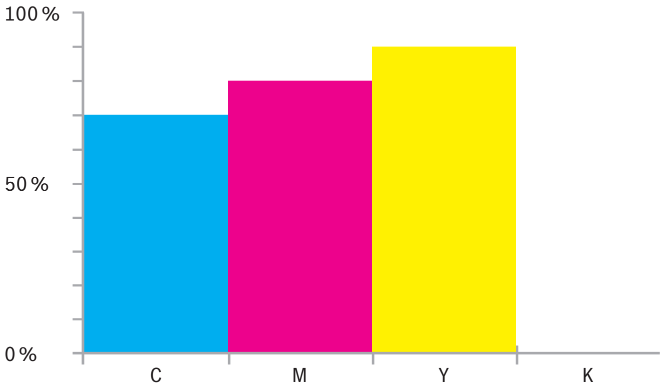
- Which inks make up the gray areas?
- How are the colored image areas made darker?
- How are shadows and image definition in the shadows produced?

In short: How are the gray or achromatic colors made up and what is the resultant maximum total area coverage?

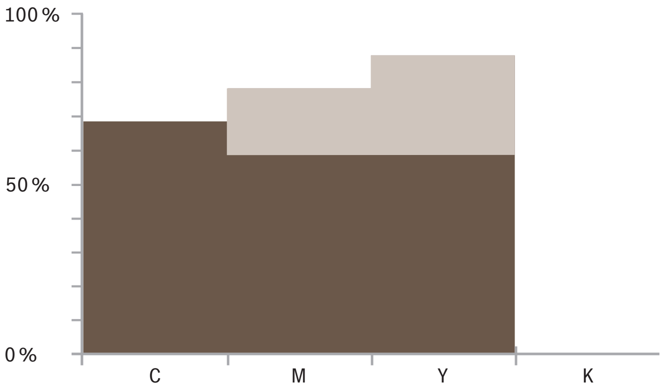
Reminder: Gray and achromatic values can either be generated from cyan, magenta and yellow or by using black ink, or any combination of all these colors. A combination is also possible.

2.4.1 Chromatic composition

In chromatic composition, all achromatic values essentially consist of subsets of the chromatic inks cyan (C), magenta (M) and yellow (Y), i.e. all gray image areas, all tertiary tones, and shadow definition contain these three chromatic colors. Black (K) is only used to support the image shadows and to enhance shadow definition (skeleton black).

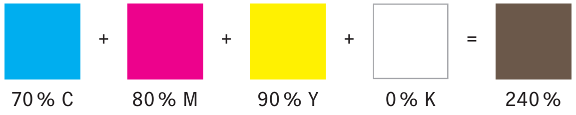


Chromatic composition



Brown in chromatic composition

The brown shown in the figure is made up of 70 % cyan, 80 % magenta, 90 % yellow and 0 % black using chromatic composition. The total area coverage is, therefore, 240 %.

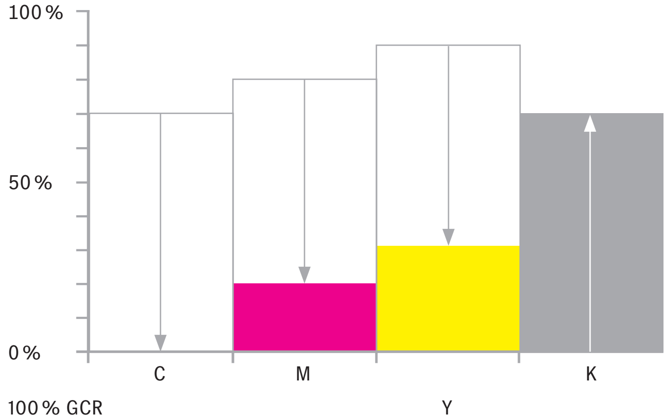


The effect of the color components can be seen opposite. The brown consists of an achromatic, gray component as well as a chromatic component. According to ISO 12647-2, 70 % cyan, 60 % magenta and 60 % yellow should produce gray when overprinted. Only the remaining 20 % magenta and 30 % yellow form the light brown component. This becomes dark brown with the addition of the gray component.

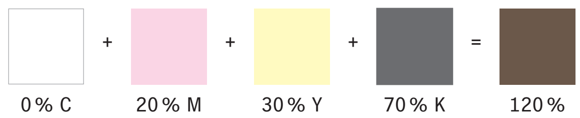
The chromatic composition results in a high total area coverage, which could theoretically amount to 400 %. In practice, such a total area coverage would rule out any reasonable color balance. The neutral gray tones in particular would tend to result in color casts in various directions, and there would also be a negative impact on ink acceptance, drying behavior, and powder consumption, as well as problems in the postpress stage.

2.4.2 Achromatic composition

Unlike chromatic composition, achromatic composition essentially involves generating all achromatic components in multicolor print images with the color black. Neutral tones, therefore, consist solely of the color black, while black is also used for shadow definition and to darken chromatic tones. All hues consist of a maximum of two chromatic colors plus black. This makes the color balance more stable. In theory, the brown from Section 2.4.1 could be created as follows using achromatic composition: 0 % C + 20 % M + 30 % Y + 70 % K. However, as the figure shows, merely replacing an achromatic shade produced with CMY with black does not produce an identical color.



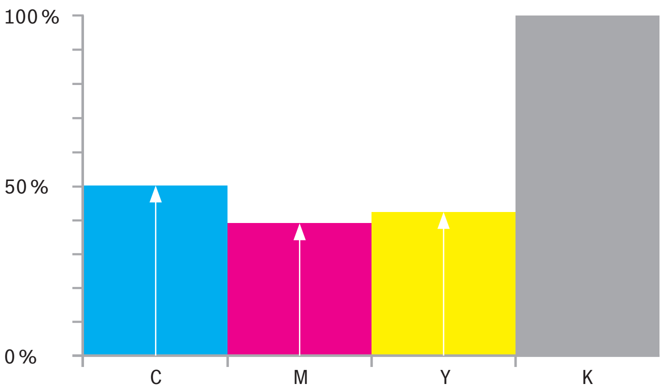
100 % GCR



This is primarily due to the shortcomings of actual printing inks. To achieve true color similarity, it is necessary to modify the proportions, e. g. to 62 % M, 80 % Y and 67 % K. The achromatic composition is the equivalent of 100 % GCR (Section 2.4.6).

2.4.3 Achromatic composition with under color addition (UCA)

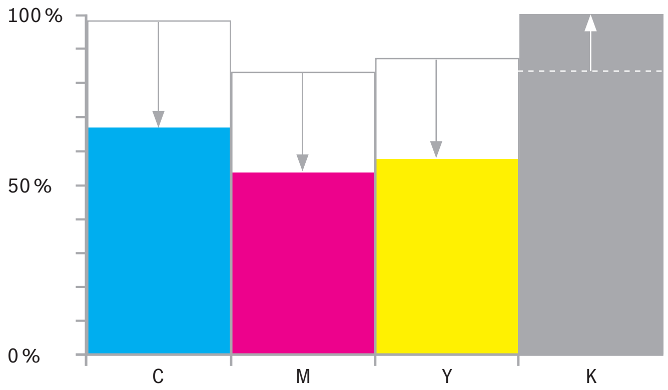
Process black by itself does not always result in sufficient definition in the darker portion of the gray axis. When this is the case, this range is toned down and the neighboring chromatic tones are enhanced with the addition of an achromatic component made up of C + M + Y. This process, known as under color addition (UCA), depends in particular on the combination of substrate and ink. The figure opposite shows UCA in the neutral image shadows.



Under color addition (UCA)

2.4.4 Chromatic composition with under color removal (UCR)

The highest total area coverage results from using chromatic composition in the neutral three-quarter tones through to black. This drawback is offset by under color removal. The achromatic component made up of C + M + Y is reduced in the neutral shadows and in the neighboring chromatic tones, while the amount of process black is increased. In the example opposite, the initial area coverage consisting of 98 % cyan + 86 % magenta + 87 % yellow + 84 % black = 355% is reduced by 78% using UCR to 68% cyan + 56 % magenta + 57 % yellow + 96 % black = 277 %. This has a positive effect on ink acceptance, drying and color balance.



Under color removal (UCR)

2.4.5 Chromatic composition with gray stabilization

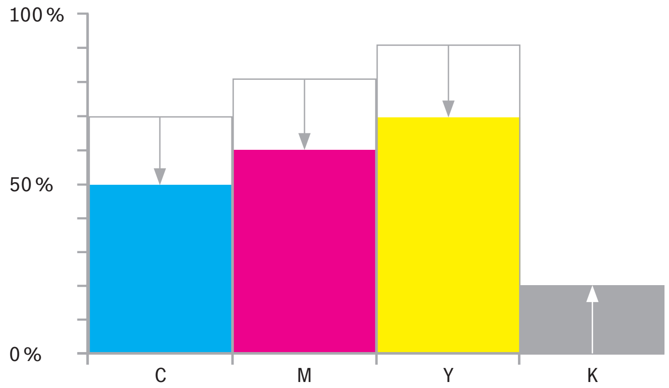
Gray tones generated with chromatic composition are difficult to keep balanced during the print process. Color casts readily occur, but can be counteracted through gray stabilization. Achromatic components generated with C+ M + Y are partially or completely replaced by an equivalent amount of black along the entire gray axis and to a lesser extent in the neighboring color ranges, i. e. not just at the darker end of the gray axis as with UCR. In practice, this is known as “long black”.

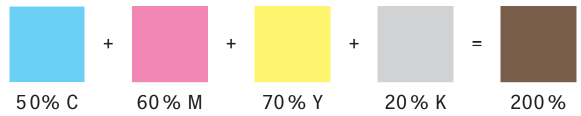
2.4.6 Chromatic composition with gray component replacement (GCR)

Gray component replacement involves using achromatic process black in both chromatic and neutral image areas to replace the components of C + M + Y that neutralize to gray. GCR can, therefore, be used for all intermediate stages between chromatic and achromatic composition in all image areas – and is not, like UCR, UCA and gray stabilization, limited to the gray areas.

Gray component replacement is also sometimes referred to as complementary color reduction.

The brown in Sections 2.4.1 and 2.4.3, for example, could theoretically be generated as follows using GCR: As with achromatic composition (Section 2.4.2), in practice, the colors obtained with the two methods are not identical if black is merely substituted for part of the achromatic CMY without adjusting the chromatic component as well. Color similarity can be achieved with, for example, 49 % C + 70 % M + 80 % Y + 30 % K.





Gray component replacement (GCR)

2.4.7 Five-, six- and seven-color printing

The modern four-color printing process ensures high quality image reproduction. However, with some originals and when extremely high quality is required, it can be necessary to use special color separations. The reproducible range of colors can be extended by using additional colors (in addition to the four primary colors) or special process colors. The coordinates measured for a seven-color print are plotted in the CIE chromaticity diagram in the figure on the right.

The hexagon on the inside shows the color gamut reproducible with the process colors cyan, magenta and yellow (as measured). The surrounding dodecagon shows the extended color gamut obtained using the additional colors green (G), red (R) and blue (B).

2.5 Ink acceptance and color sequence

2.5.1 Ink acceptance

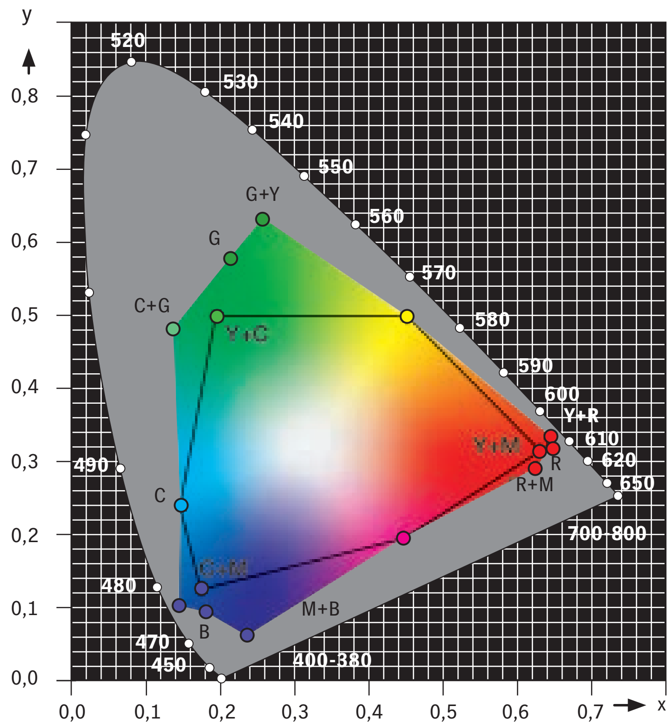
Another variable that influences color reproduction is ink acceptance, also known as ink trapping. It is a measure of how well an ink is transferred to a printed substrate in comparison to an unprinted substrate. It is important here to distinguish between wet-on-dry and wet-on-wet printing.

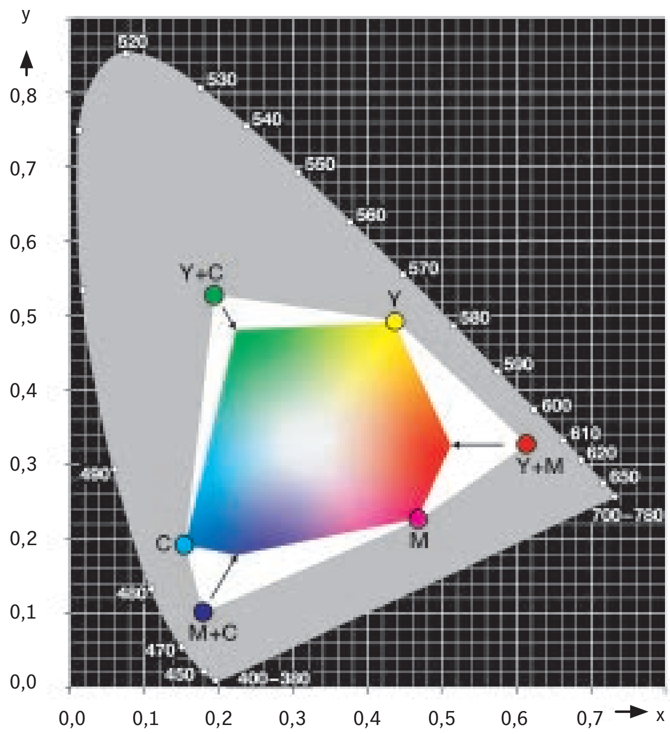
Wet-on-dry printing is when an ink is laid down directly on the substrate or onto a previously printed and dried ink film. If the ink is applied to an ink that is still wet, however, this is known as wet-on-wet printing. Wet-on-wet printing has become the term of choice when we discuss printing on multicolor presses.

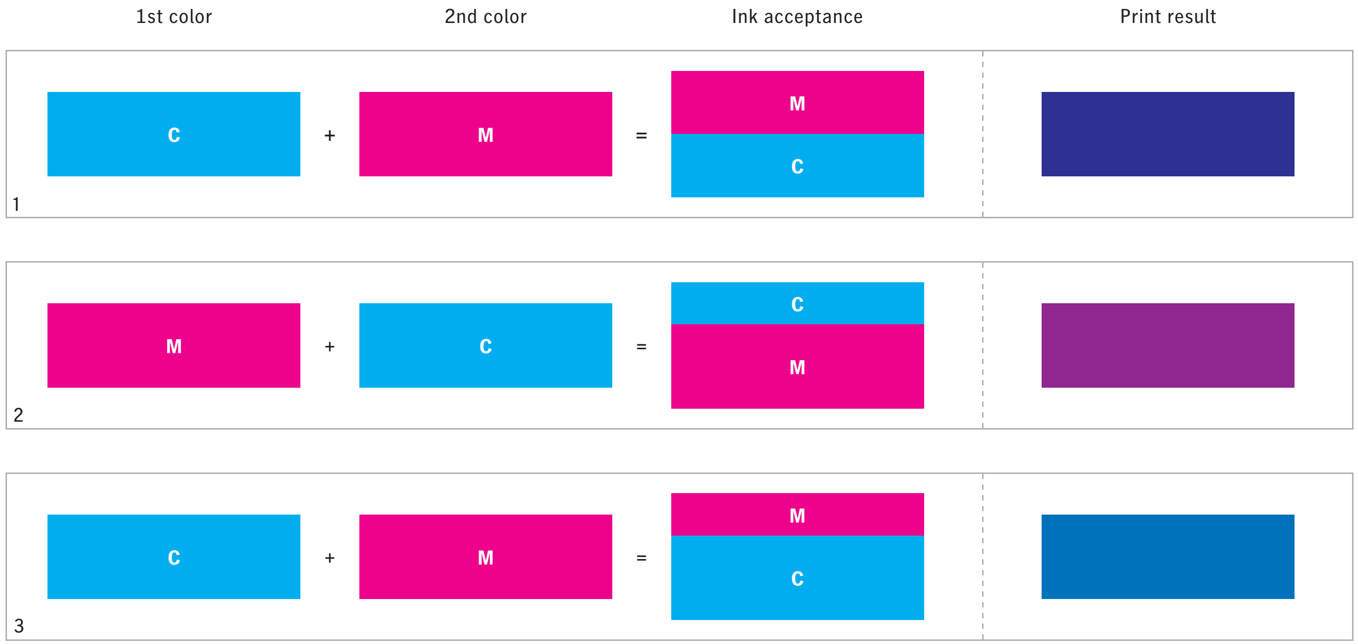
When inking is uniform and the color coordinates for the required hue are correct, we talk about good ink acceptance behavior.

In contrast, if the required hue cannot be achieved, then the ink acceptance behavior is poor. This can happen with all mixed colors. As a result, the color gamut is reduced and certain color shades can no longer be reproduced.

Even if the right ink film thicknesses are printed in a given color set and the color coordinates of the primary printing colors cyan, magenta and yellow are on target, it may still be impossible to achieve the target color coordinates of the mixed colors red, green and blue due to overprinting problems.







Examples of two colors being overprinted in different ways.

The CIE chromaticity diagram above shows the effect that impaired ink acceptance behavior or an unsuitable color sequence can have on the print result. The white area illustrates the extent to which the tonal value has decreased as a result of ink acceptance problems.

2.5.2 Color sequence

The schematic representation illustrates three different sequences for overprinting the colors cyan and magenta. Example 1 shows the print result on a single color press. First, cyan was printed on the white paper. Then magenta was printed on the dry cyan. The result is a saturated blue.

The second example was created on a multicolor press. First, magenta was printed onto the dry paper (wet-on-dry), followed by cyan on the still moist magenta (wet-on-wet). While the paper absorbed magenta well, the ink acceptance behavior for cyan was not as good (due to the ink splitting that occurred during overprinting). This resulted in a blue with a red cast.

The third example was also printed wet-on-wet, but in the reverse sequence (magenta on cyan). This prevents the red cast.

ISO 12647-2 specifies the color sequence black – cyan – magenta – yellow for four-color printing. A careful inspection of both the original and the plates before mounting can reduce the effects of ink acceptance problems in critical cases. When printing solids, it may also be useful, for example, to print the lighter form with less ink coverage before the heavier one.

This applies especially when halftone areas and solids are printed on top of each other. In this case, the halftone should be printed first on the white paper and then the solid on top.

2.6 Print control strips

To assess the print quality through measurement, print control strips are included in the printed sheets. They are normally positioned either at the sheet's lead edge, tail edge or in the center. The central position is the preferred one for perfecting presses and impositioned sheets.

Print control strips in digital form are available from Fogra and various other vendors. Heidelberg has been marketing its DIPCO (Digital Print Control Elements) package for many years. In addition to conventional print control strips, the DIPCO package also includes the so-called Mini Spots for color and process control. All DIPCO strips can be used in both manual assembly and as color marks in automatic assembly with Prinect® Signa Station® .

If the print control strips are used for automatic process calibration of the printing plates in CTP, they must always be located in the same position! Otherwise, the measurement results may be incorrect, and this can result in erroneous imaging.

Which print control strips are used depends primarily on the colors required for the job. Standard print control strips have a minimum of four colors. If fewer colors are printed, the unused patches remain empty. Another important criterion is the color measurement device used. The size of the measurement patches depends on the diameter of the measurement aperture. There are limits as to how small this aperture can be, since it must also be able to reliably measure the tonal values of the halftone patches. According to ISO 12647, the measurement aperture should correspond to 15 times the screen frequency, or at least a minimum of 10 times this value, i. e. 80 l/cm = 0.125 mm line definition. The minimum size of the measurement aperture is therefore 0.125 × 15 = 1.875 mm.

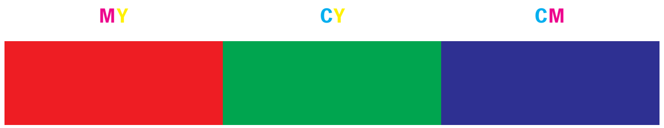
All print control strips consist of several different measurement patches as described below.

2.6.1 Solid patches

Solid patches are used to monitor the consistency of inking. It is good practice to use one solid patch for each color, spaced to correspond to the width of the ink zones (32.5 mm in Heidelberg presses). Solid patches can then be used for automatic control of the solids.

2.6.2 Solid overprint patches

These patches are used to evaluate ink acceptance by means of visual inspection and measurement.



2.6.3 Color balance patches

There are color balance patches for both solids and halftones.

Overprinting the colors cyan, magenta and yellow should result in a relatively neutral black. For comparison purposes, a solid black patch is printed alongside the overprint patch.

With the correct ink film thickness, standard color sequence and normal dot gain, the halftone patches for cyan, magenta and yellow should result in a fairly neutral gray when overprinted.

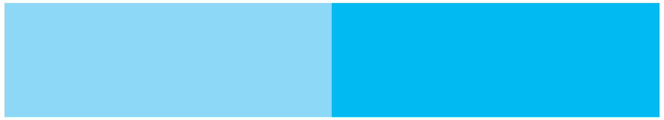
Color balance patches are used for visual checks, as well as automatic gray balance color control for the colors cyan, magenta and yellow.

The standardized print process according to ISO 12647-2 specifies that gray balance must be achieved primarily by using ICC color profiles to generate the separations.

2.6.4 Halftone patches

The tonal values of the halftone patches vary depending on the manufacturer.

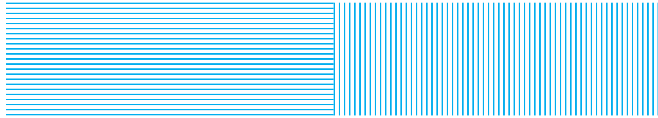
The values measured in the halftone and solid patches are used to calculate dot gain and relative print contrast.

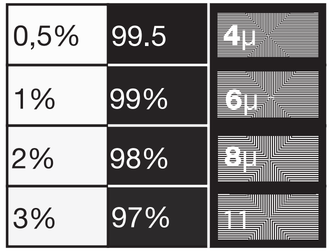


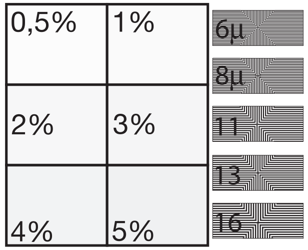
Today, print control strips with 40 % and 80 % measurement patches are the most widely used.

2.6.5 Slurring and doubling patches

Line screens with different angles are used to check for slurring and doubling errors, either visually or by measurement (see Section 2.2.1).







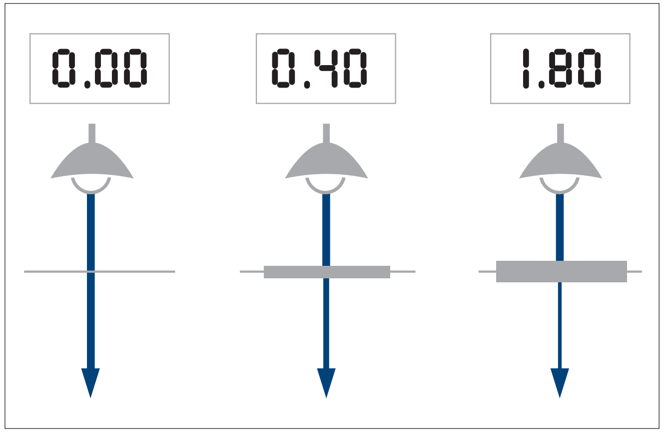
3 Densitometry.

Densitometry is a method for monitoring solid density and tonal values in the print process. It works reliably in black and white reproductions and with the process colors cyan, magenta, yellow and black.

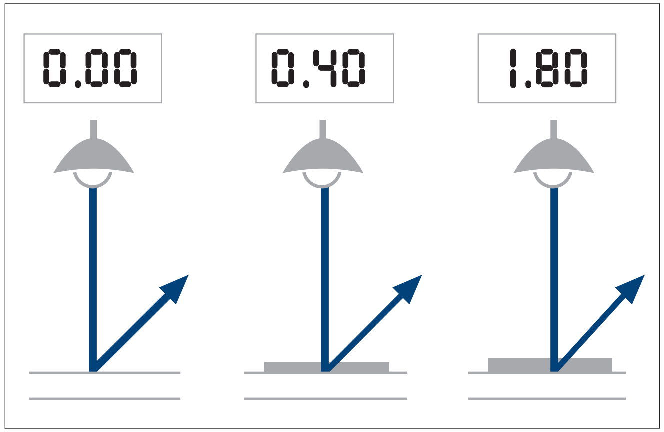
There are two types of densitometer depending on the particular application:

- Transmission densitometers are used to measure the degree of darkness in a film (i. e. with transparent copy).
- Reflection densitometers are used to measure the light reflected from the surface of a print (i. e. with reflective copy).

The following section looks at the technology behind reflection densitometers.



Transmission densitometer

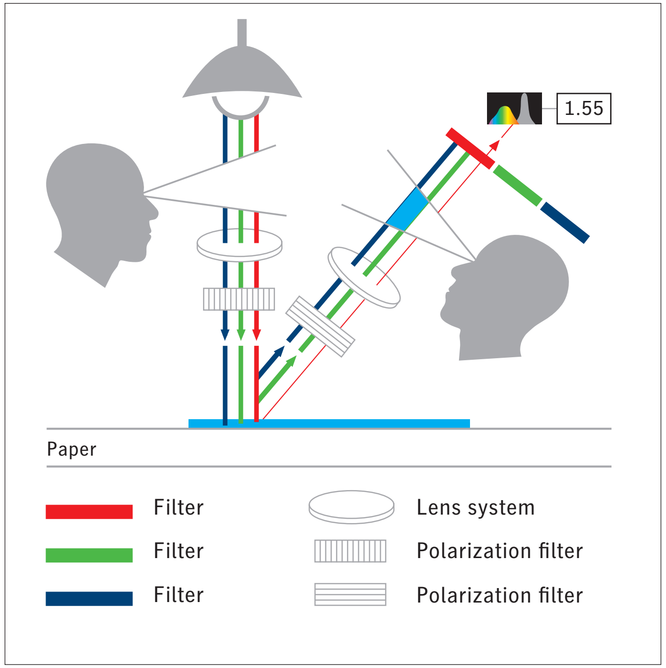


Reflection densitometer

3.1 Measuring principle of the reflection densitometer

Reflection densitometry uses a light source to illuminate the ink being measured. The light beam penetrates the translucent ink film and is attenuated in the process. The rest of the light is scattered by the paper substrate. Part of this remitted light travels through the ink film again and is further attenuated. The remainder of the light finally reaches the measurement device, which converts the light into electrical energy. The result of reflection densitometry is specified in density units.

Lens systems are used in the measurement process for bundling the light. Polarization filters suppress the wet gloss (see Section 3.2.2). Color filters are inserted in front of the densitometer when chromatic colors are measured (see Section 3.2.1).



Densitometric measurement principle

The figure shows how reflection densitometry works, using a printed chromatic color as an example. The white light applied ideally consists of equal proportions of red, green and blue. The printed ink contains pigments that absorb red and reflect green and blue, which is why we call it cyan. We use the densitometer to measure in the absorption range of each color, because density and ink film thickness are well correlated there. The example, therefore, uses a red filter, which blocks blue and green and only allows red to pass through.

The density of an ink depends primarily on the type of pigment, the concentration of pigments and the ink film thickness. The ink density for a specific ink may be a measure of the film thickness but it provides no indication of the hue.

3.2 Filters in the densitometer

3.2.1 Color and brightness filters

The color filters in a densitometer are optimized for the absorption behavior of cyan, magenta and yellow.

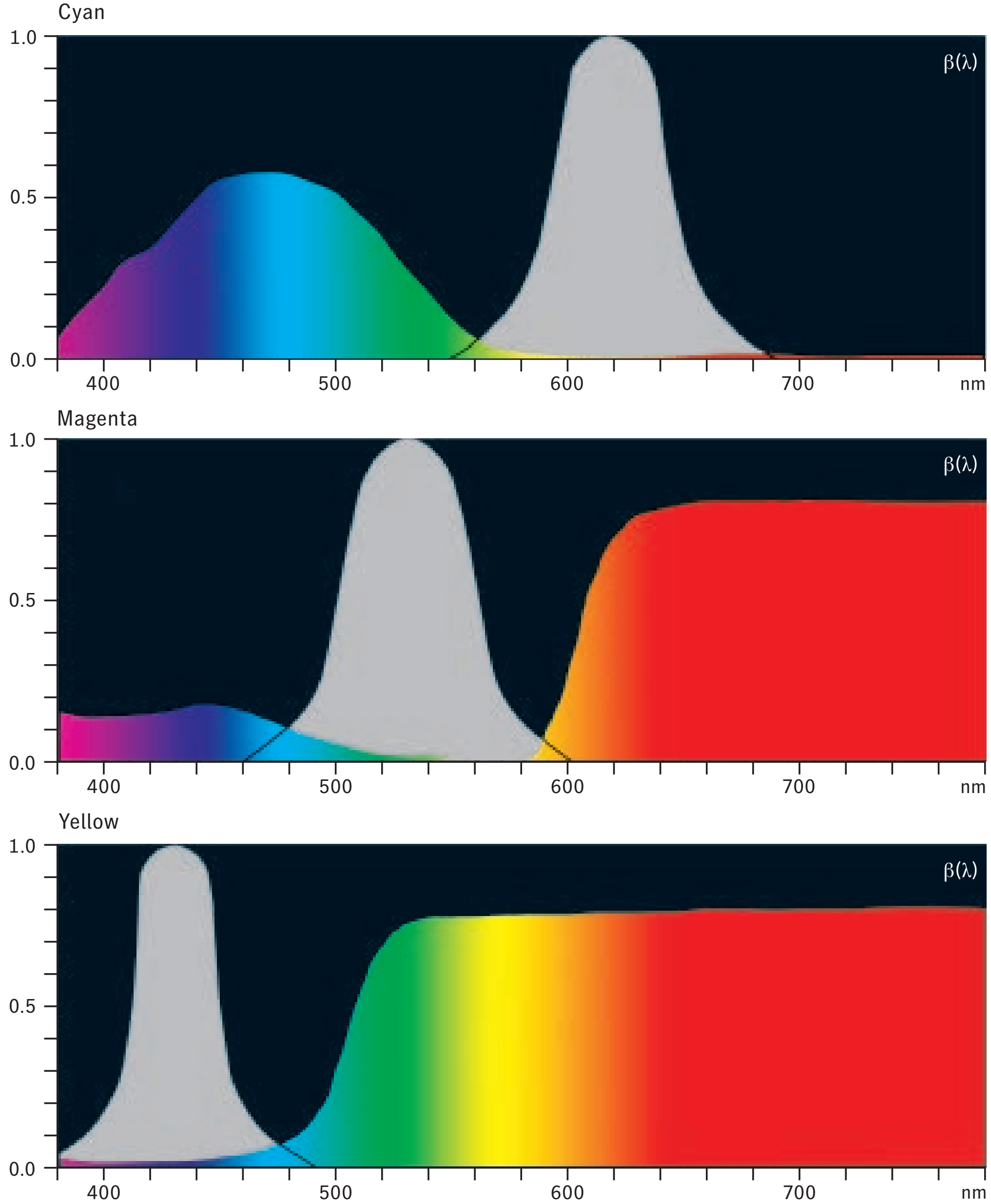
The spectral pass bands and the location of the pass maxima are defined in ISO 5-3. The filter names were standardized and incorporated in the Heidelberg color measuring systems in 2009. The following correlations apply:
ISO 5-3 Status E = DIN 16536
ISO 5-3 Status I = DIN 16536 NB
ISO 5-3 Status T = ANSI Status T

The filter ISO 5-3 Status E must be used for measurements according to ISO 12647-2.

Always choose a color filter that is complementary to the color being measured. Black is evaluated with a filter that has been adapted to the spectral brightness sensitivity of the human eye. Spot colors are measured with the filter that produces the highest measurement value.

The following three figures (on the next page) show the reflection curves for cyan, magenta and yellow using the corresponding color filters as defined by ISO 5-3.

Printed color	Filter color
Cyan	Red
Magenta	Green
Yellow	Blue



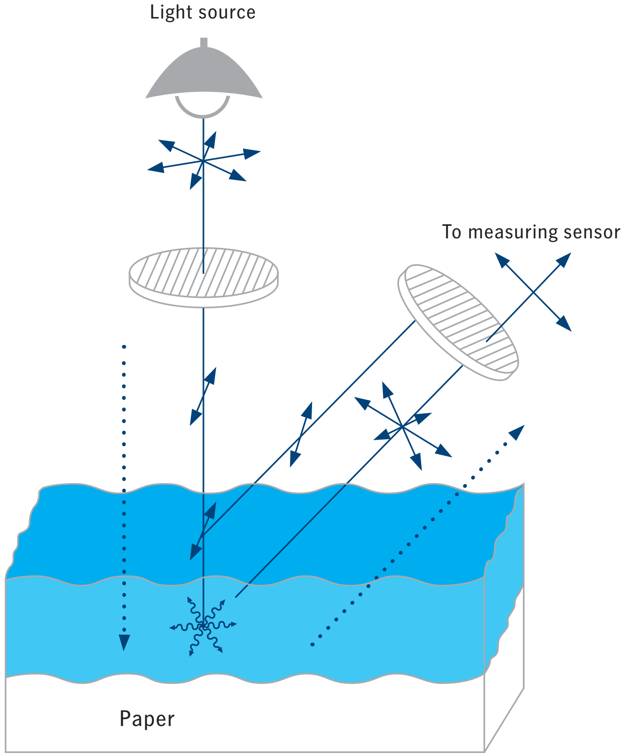
Reflection curves for cyan, magenta and yellow with their corresponding color filters as defined by ISO 5-3

3.2.2 Polarization filters

When sheets are pulled freshly printed from the delivery and measured, the ink is still wet and has a shiny surface. As it dries, the ink penetrates the paper (absorption) and loses its gloss. This not only changes the ink's hue, but also its density. This means the press operator can only use density to a limited extent to compare wet sheets with the reference values, because the reference values generally refer to dry ink.

To remedy this problem, two linear polarization filters at right angles to one another are placed in the optical path of the densitometer. Light waves oscillate in all directions but polarization filters only permit the light waves that oscillate in a certain plane to pass through. Some of the light beams allowed through by the first polarization filter are reflected back from the wet ink's glossy surface but their oscillation plane remains unchanged. The second polarization filter is rotated 90° in relation to the first filter, which blocks the reflected light waves.

However, if the light is only reflected after it has penetrated the ink film and is reflected back by the ink film or finally by the substrate, it loses its uniform direction of oscillation (polarization). Consequently, some of it passes through the second polarization filter and can be measured. Filtering out the light reflected by the glossy surface of the wet ink, therefore, has the effect of making the densitometric measurement values for wet and dry ink roughly equivalent.



Direction of scattering
Direction of oscillation
Functioning principle of polarization filters

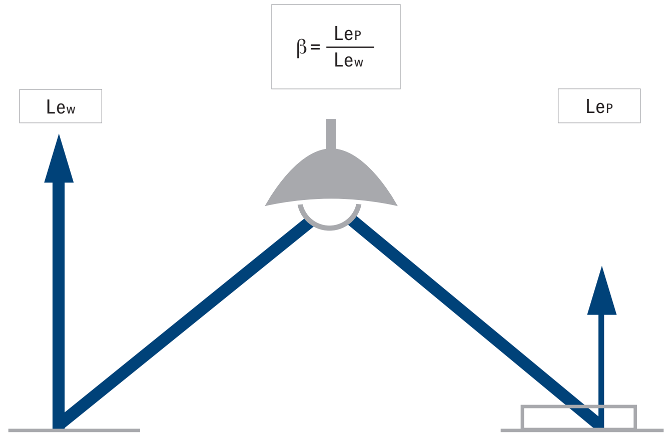
3.3 Densitometric measurement values

Densitometers measure the ink density (D), expressed as the logarithmic relationship of light absorption by a reference white to light absorption of the ink film H_2.

The following equation is used to calculate ink density:

$$D = \lg \frac{1}{\beta}$$

The reflectance (also called the beta value) is calculated as follows:



$$\beta = \frac{Le_P}{Le_W} = \frac{50\,\%}{100\,\%} = 0.5$$

LeP is the light reflected by the measured ink and LeW is the light reflected by the reference white.

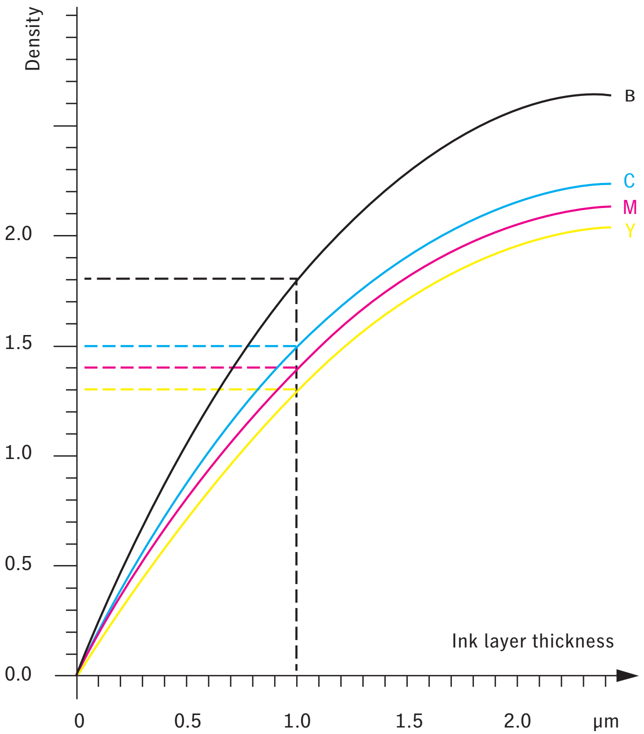
The reflectance (ß) indicates the ratio between the light reflected by a sample (the printed ink) and a standard white (reference value).

The above ß value produces the following density:

$$D = \lg \frac{1}{\beta} = \lg \frac{1}{0{,}5} = \lg 2 = 0.30$$

The graph below shows how the ink film thickness and density correlate for the four process colors used in offset printing.

The dotted vertical line shows the approximately one micrometer ink film thickness usually used in offset printing. This graph shows that the density curves only flatten out at much higher values. Above these thicknesses, there is hardly any further increase in density; even if you measured a full can of ink, the value obtained would be no higher. However, ink films this thick are of no relevance to the standard four-color process.



Process colors in offset printing

There is a close correlation between ink film thickness and ink density. The graph shows that reflection diminishes and density increases as the ink film becomes thicker.

See page 32 for the equations for calculating this.

3.4 Measurement

3.4.1 Calibration to paper white

Before any measurements are carried out, densitometers are calibrated to the applicable paper white (reference white) to eliminate the influence of the paper color and its surface when the printed ink film thickness is evaluated.

The density of paper white is measured relative to “absolute white” and this value is then set to 0 (the reading is D = 0.00). One exception to this rule is in North America, which has a regulation defining the calibration of the densitometer to absolute white.

3.4.2 Solid density

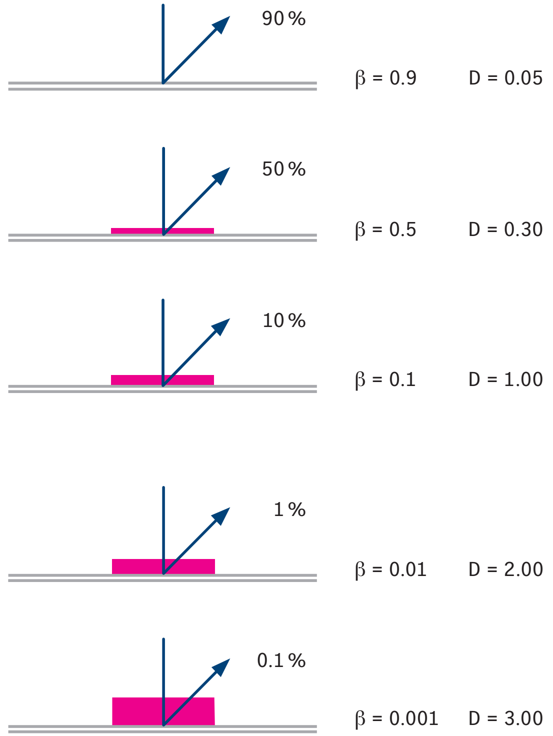
The values measured in a solid area indicate the solid density (SD). This is measured in a print control strip that is printed on the sheet crosswise to the printing direction and has a number of patches, including solid patches for all four process colors (and spot colors, if required).

The solid density can be used to control and maintain a uniform ink film thickness across the entire width of the sheet and throughout the print run (within certain tolerances).

3.4.3 Halftone density

Halftone density is measured in the halftone patches of the print control strip by capturing a combination of the halftone dots and the paper white. This is also referred to as an integral measurement.

The measured value is the halftone density (HD). This value increases with the proportion of halftone dots in the measured patch and with the ink film thickness.



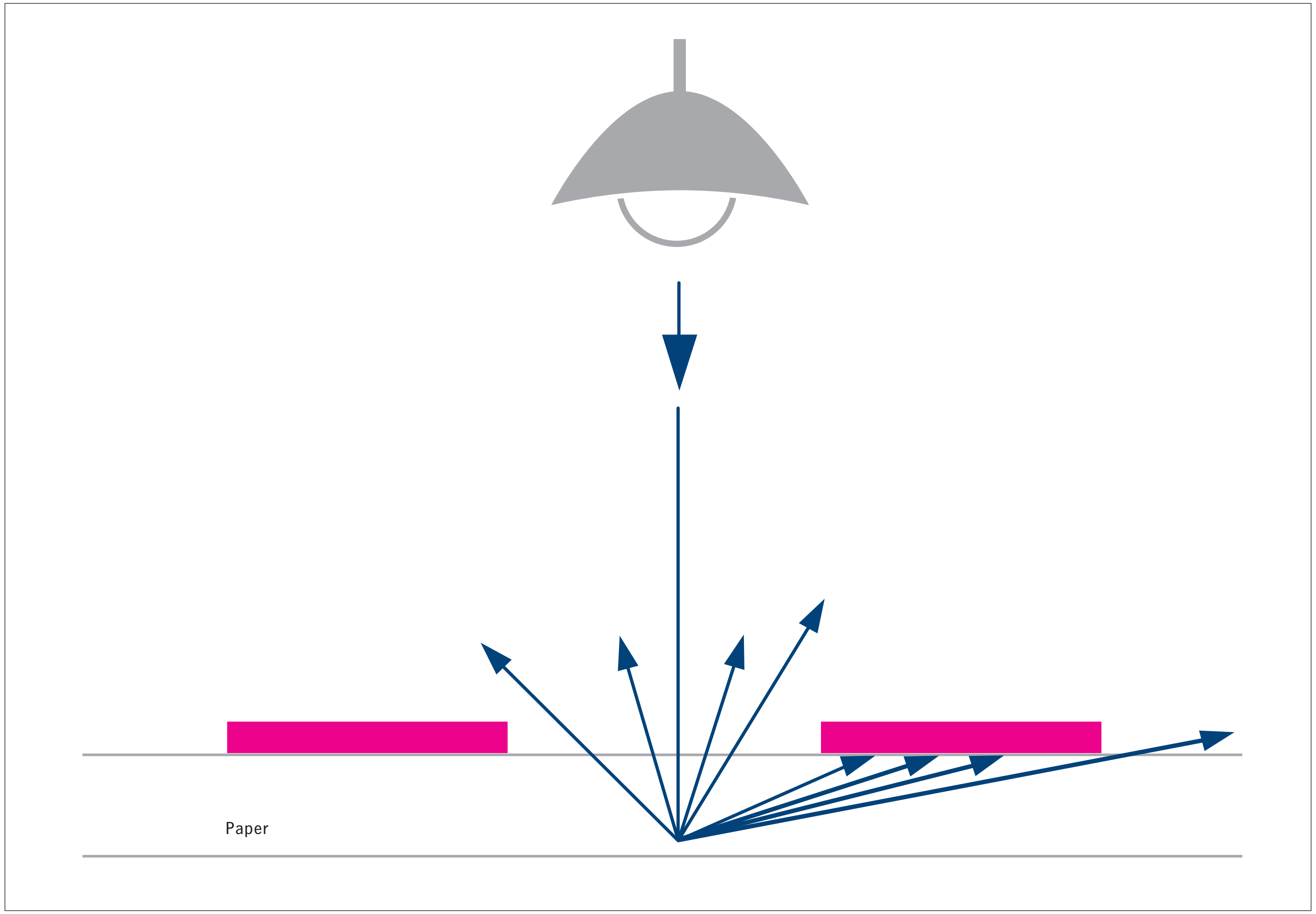
Examples of halftone density

3.4.4 Optically effective area coverage (halftone value)

When halftone images are measured using densitometry it is not the geometric area coverage (the percentage of the patch's surface covered by halftone dots) that is measured, but rather the "optically effective area coverage".

The difference between geometric and optically effective area coverage is due to the fact that, regardless of whether image areas are checked visually or measured with a densitometer, some of the arriving light penetrates the paper in the blank areas between the halftone dots and some of the reflected light strikes the back of the dots and is absorbed by them.

This effect is also called a "light trap". It makes the halftone dots appear larger than they are in reality. The optically effective area coverage, therefore, consists of the geometrical area coverage plus the optical area increase.



Optically effective area coverage

3.5 Evaluation

The densitometric values measured for the solids and halftones can be used to calculate halftone value, dot gain and contrast – provided the densitometer has first been calibrated to paper white.

3.5.1 Halftone value

The halftone value in the print run FD can be determined from the measured solid and halftone densities (SD and HD) as follows using the Murray-Davies equation:

$$F_D(\%) = \frac{1-10^{-DR}}{1-10^{-DV}} \cdot 100$$

3.5.2 Dot gain

The dot gain (DG) is the difference between the measured halftone value in the print run (FD) and the known halftone value in the film (FF) or digital data.

$$TWZ\ (\%) = F_D - F_F$$

3.5.3 Relative print contrast

The relative print contrast (C) is also calculated from the measured solid density (SD) and the halftone density (HD). The HD value is best measured in three-quarter tones.

$$K_{rel.}\ (\%) = \frac{DV - DR}{DV} \cdot 100$$

3.5.4 Trapping

Trapping is calculated from the densities measured in single-color solid and two- and three-color overprint patches, taking into the account the ink printing sequence.

The trapping calculated using the following equations indicates what percentage of a color is overprinted on another color. It is compared with the color applied first, the trapping of which is assumed to be 100 %.

3.5.4.1 Overprinting two colors

With this type of printing

D1+2 is the density of the two overprinted colors

D1 is the density of the first printed color and

D2 is the density of the second printed color

Please note: All densities must be measured using the color filter that is complementary to the second color.

$$F_{\substack{2\\1}}(\%) = \frac{D_{1+2} - D_1}{D_2} \cdot 100$$

3.5.4.2 Overprinting three colors

With this type of printing

D1+2+3 is the density of all three overprinted colors and

D3 is the density of the third printed color

$$F_{\substack{3\\2\\1}}(\%) = \frac{D_{1+2+3} - D_{1+2}}{D_3} \cdot 100$$

Please note: All densities must be measured using the colored filter that is diametrically opposite the third color (complementary).

The equations given here are also used by all Heidelberg color measuring systems. There are also other methods for determining ink acceptance. All these methods are controversial and, consequently, the results produced should not be taken too seriously. They are, however, useful for comparing print runs and in particular for comparing sheets pulled from the same run. The higher the ink acceptance value, the better the ink acceptance behavior.

Functional range of measuring systems

	Densitometer	Spectrophotometer
Mixing of spot colors		•
Inking setup		
According to standards	∘ (•)	∘ •
Using print control strips	∘ (•)	∘ •
Using colorimetric values (L*a*b*)		∘ •
Using proofs		∘ •
According to samples		∘ •
According to image data		∘ •
Assessing ink suitability		∘ •
Adjusting inking		∘ •
Production print run control		
According to solid patches	∘ (•)	∘ •
According to single-color halftone patches	∘ (•)	∘ •
According to multicolor halftone patches		∘ •
According to in-image measurements		∘ •
Detecting ink soiling		∘ •
Detecting changes in substrate		∘ •
Measurement values		
Solid density	∘ (•)	∘ •
Tonal value/dot gain	∘ (•)	∘ •
Relative trapping	∘ (•)	∘ •
Absolute trapping		∘ •
Metamerism		∘ •
Visual perception		∘ •

∘ suitable for standard colors • suitable for spot colors (•) limited suitability

3.6 The limits of densitometry

Densitometers operate on principles similar to those for creating color separations, using special filters geared specifically to the four process colors. They provide a relative measure of the ink film thickness, but do not reveal anything that directly correlates to human color perception.

Consequently, their applications are limited. The table on page 33 shows their typical applications as compared to spectrophotometers.

One major constraint on densitometry is that the same ink densities do not necessarily make for the same visual impressions. This is always the case when different color substances are compared. That is why proofs, test prints on different paper and/or with ink other than the ink to be used in the production run, or any other samples cannot be used as reliable reference values for adjusting the ink settings in the press when printing on production paper.

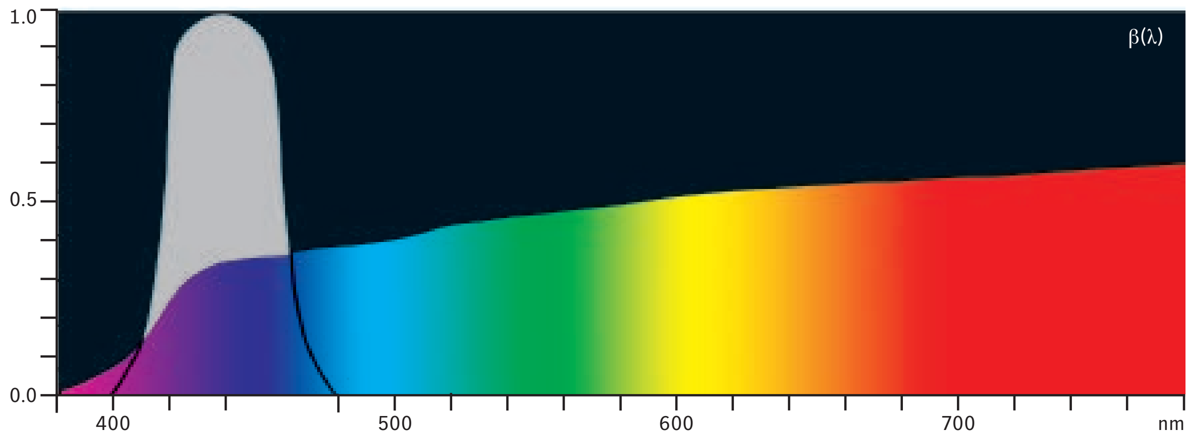
Another significant constraint is that densitometers operate only with the three color filters red, green and blue. As soon as color sets are produced with more than the four process colors, problems arise when the additional colors are measured. Since there are no filters defined for these additional colors that work in their absorption range, the ink density and dot gain values are less informative.

The use of densitometers also proves problematic for regulating inking based on multicolor halftone patches (e. g. gray patches). Measuring a gray patch with all three color filters produces different ink densities than measuring each color individually.

Each of the three colors contributes to all ink densities to a greater or lesser extent. This is because process colors are not pure primary colors that each represent two-thirds of the spectrum and, therefore, also absorb light in other wavelengths. Densitometers are used for monitoring quality in production runs using the four-color printing process, but they are only of limited use in all other applications.

To counteract these limitations, many manufacturers today market so-called spectrodensitometers. In principle, they are similar to spectrophotometers when it comes to hardware and measurement technology, but they only deliver density values. These devices not only use four filters for measuring the densities for spot colors, but also a spectral filter that finds the highest absorption (lowest remission) in the spectrum.

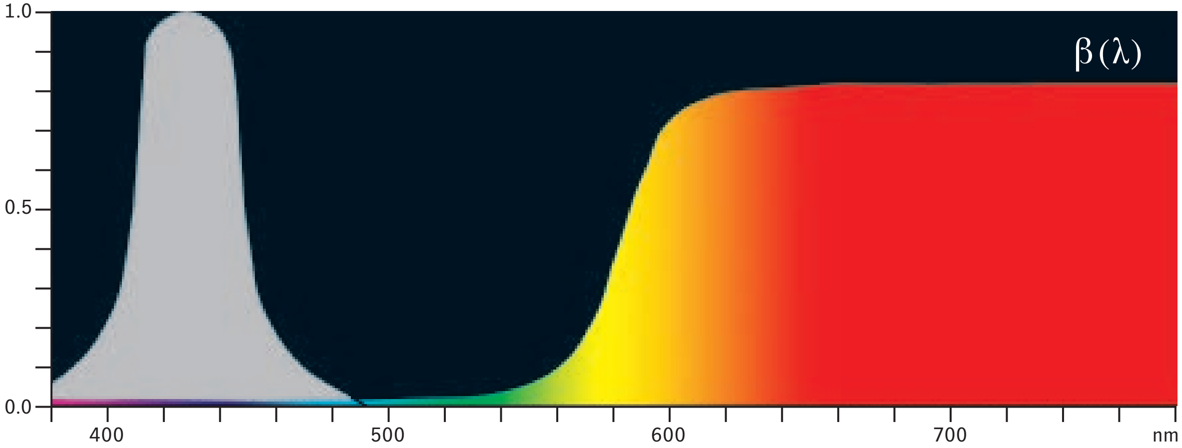
As can be seen in the diagram above, the hue shown here (Pantone Warm Gray 1) has a relatively high remission, which falls away slightly in the blue spectrum (380 to 500 nanometers). Accordingly, the highest density value (0.27) is measured with a blue filter (0.27).



Color sample: Pantone Warm Gray 1

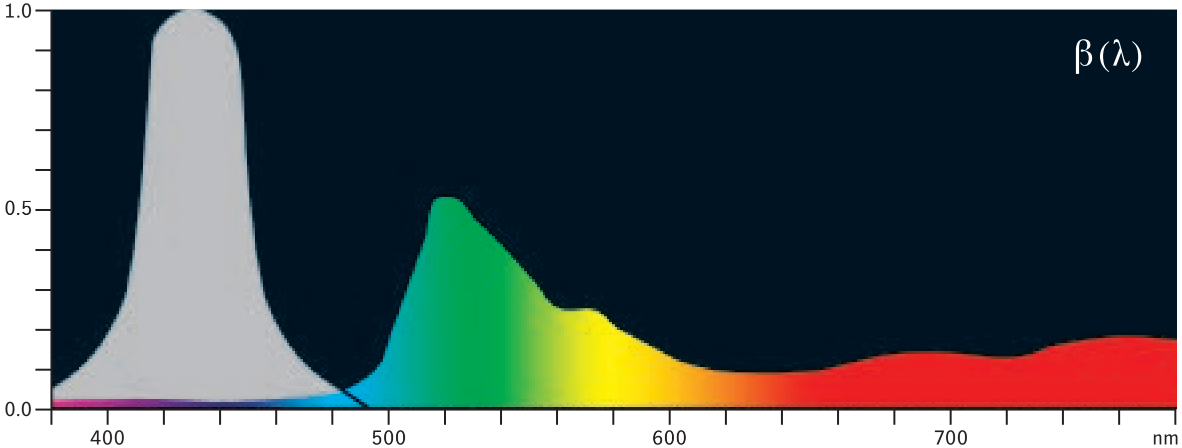
The spot colors HKS 8 and HKS 65 in the second and third examples have radically different hues. This is also evident in their remission curves. However, both colors have the greatest absorption in the blue spectrum (380 to 500 nanometers), which means that once again the highest density value (1.60 in each case) is measured with the blue filter. This shows that density values measured with the same color filter in no way yield the same color tones!

Only colorimetric measurements can tell us something about a color’s appearance.



Color sample: HKS 8

Density (blue filter) = 1.60
L* = 62.0
a* = 61.4
b* = 72.4



Color sample: HKS 65

Density (blue filter) = 1.60
L* = 58.7
a* = −58.8
b* = 59.7

4 Colorimetry.

As explained in the section on color systems, three parameters are needed to describe a color unambiguously. Colorimetry tells us how to obtain these values and how they are interrelated.

4.1 Measuring color

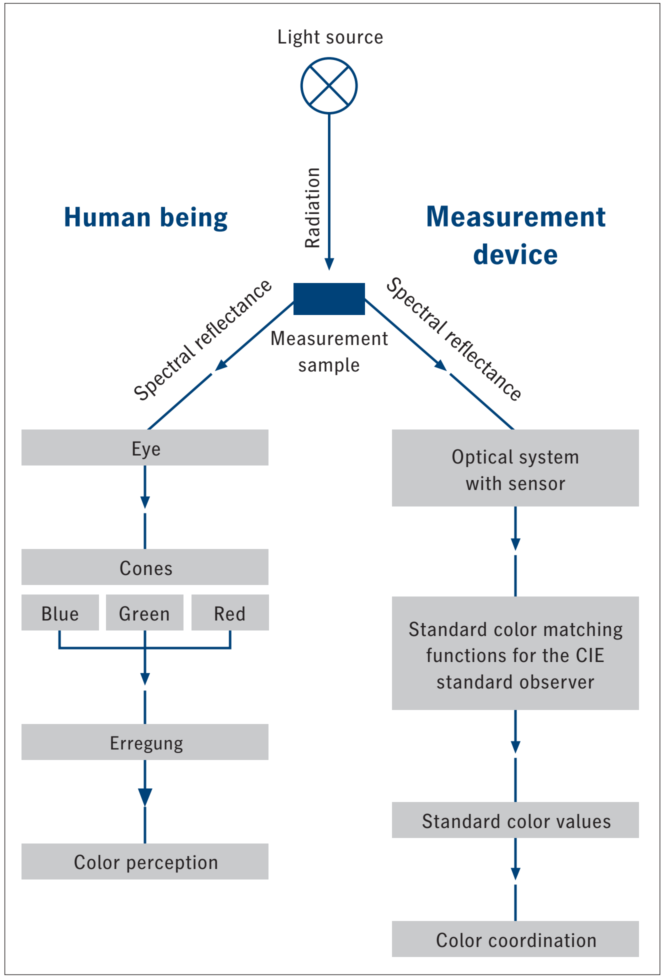
We use spectrophotometers to measure colors.

The principle of color measuring devices is based on how we humans perceive color (see figure).

A color (sample) is illuminated by a light source (radiation). Part of this light is absorbed by the sample, while the rest is reflected. The reflected light is the light our eyes perceive because it stimulates the cones (color receptors) sensitive to red, green and blue.

This stimulation results in electric signals being sent via the optic nerve to the brain, which interprets them as colors.

The measurement device emulates this natural process. To perform a measurement, the printed sample is illuminated. The reflected light passes through the system's optics and reaches a sensor. This sensor measures the light received for each color and relays the results to a processor, where the data is weighted using algorithms that simulate the action of the three types of cones in the human eye. These algorithms have been defined by the CIE for the standard observer. This results in three standardized color values – X, Y and Z – which are then converted into coordinates for the CIE chromaticity diagram or another color space (e. g. CIELab or CIE-LUV).



Comparison between a person and a spectrophotometer

4.2 Standard color values

Before you can measure colors, standard color values need to be determined based on measured reflectance under standardized conditions. Three factors are variable when non-luminous colors are measured; these factors must be set by the user: reference white, type of light (illuminant) and the viewing angle.

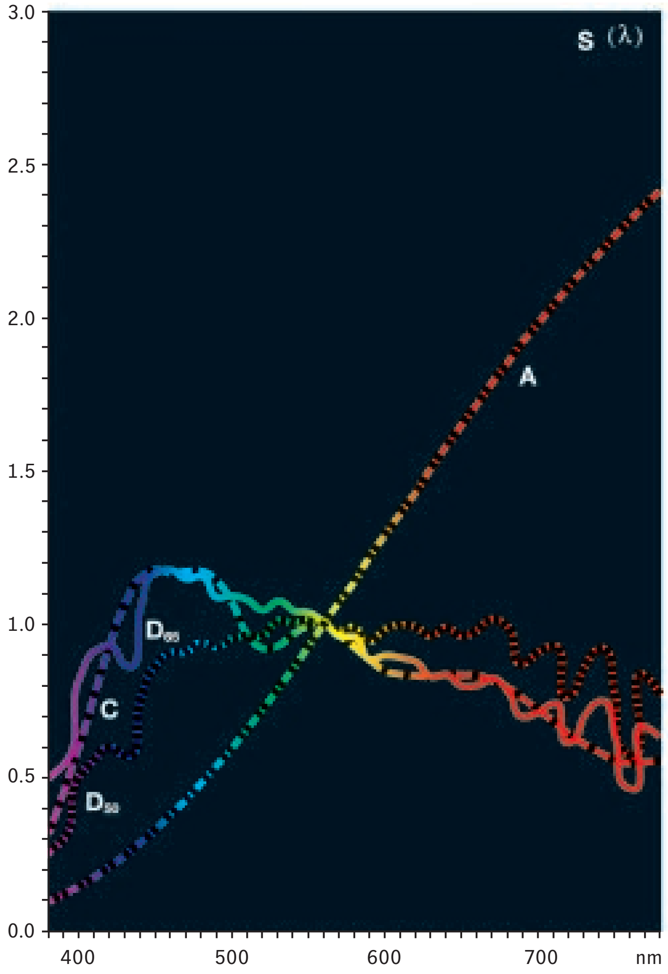
Normally, colorimetric values are based on “absolute white”. They are calibrated to the measuring device’s standard white (usually a ceramic surface), which in turn is calibrated to an absolute white.

4.3 Standard illuminants

Without light there is no color. This means, however that the type of light also plays a role in how we perceive color. The color of light is defined by its spectral composition.

The spectral composition of natural sunlight is influenced by the weather, the season and the time of day. Photographers and film makers often have to wait for a long time before the light is ideal.

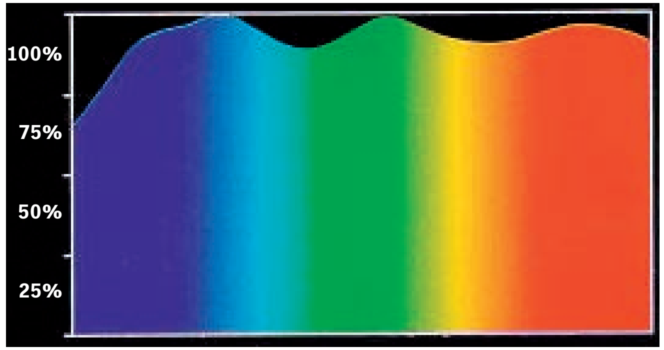
The spectral composition of artificial light also varies. Some lamps emit reddish light, while others tend more towards green or blue.



Types of illuminants

Lighting conditions affect spectral reflectance and, therefore, color perception. This means standard color values need to be based on standard lighting conditions.

For standardization purposes, the spectral distribution (intensity) of various illuminants has been defined in the wavelength range of 380 to 780 nanometers. The figure on the left shows the spectral distribution for the standard illuminants A, C, D50 and D65.



Spectral distribution

The standard illuminant D50 is similar to average daylight with the greatest radiation intensity in the blue region. The figure above shows illuminant D50.

4.4 Standard observer/Color matching functions

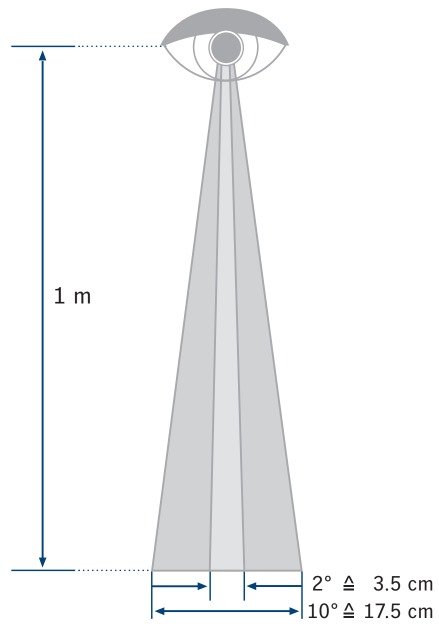
Every human retina has three types of cones, each with a different spectral sensitivity. Everyone with normal color vision perceives color resulting from the specific sensitivity of the cones in a similar way. Colors are, therefore, only perceived differently from person to person in exceptional cases. For example, a color may appear bluish-green to some but greenish-blue to others.

For colorimetric purposes, it is, therefore, essential to define a person with an average perception of colors to even out the individual differences in color perception. This person is known as the “standard observer”. In 1931, experiments were carried out using people with normal color vision.

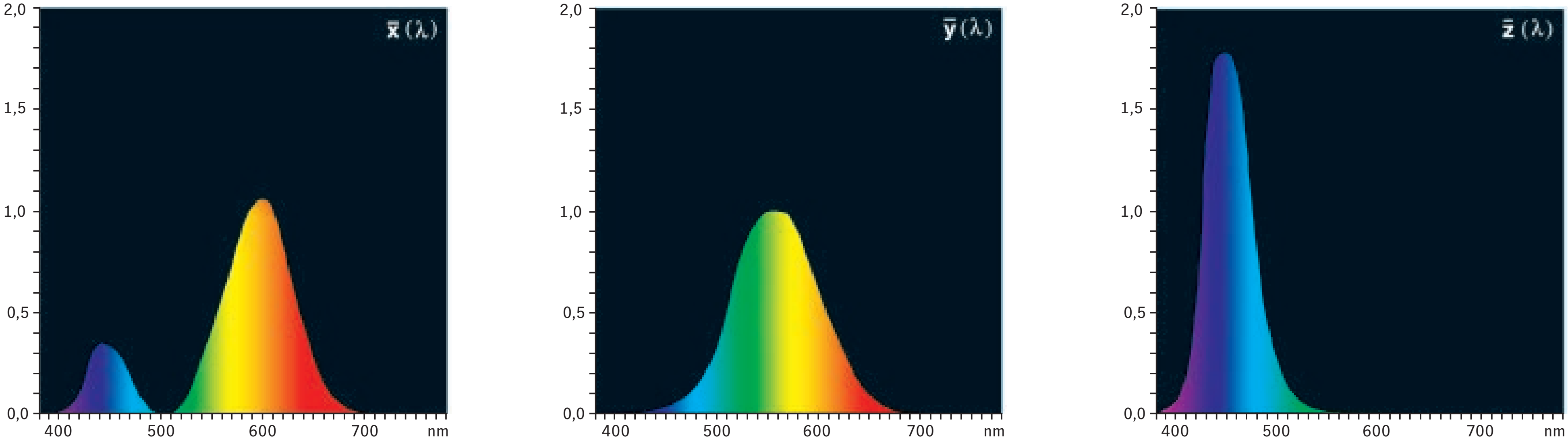
The findings were used to derive the standard color matching functions $\bar{x}$, $\bar{y}$ and $\bar{z}$ specified by the CIE, which have been made binding by national and international standards such as DIN 5033 and ISO 12647.

These experiments were conducted using an observer’s field of view through a 2° angle. Colorimetric standards interpret “field of view” as being the viewing angle through which the human eye can see a colored area (see figure on the right). If, for example, an area with a diameter of 3.5 centimeters is viewed from a distance of one meter, the angle of the observer’s field of view is 2°.

The tests were repeated in 1964 for viewing through a 10° angle, and these results were also defined in a standard. This “10º Standard Observer” standard is, however, not used in the printing industry.



2° and 10° standard observer



The color matching functions x, y and z.

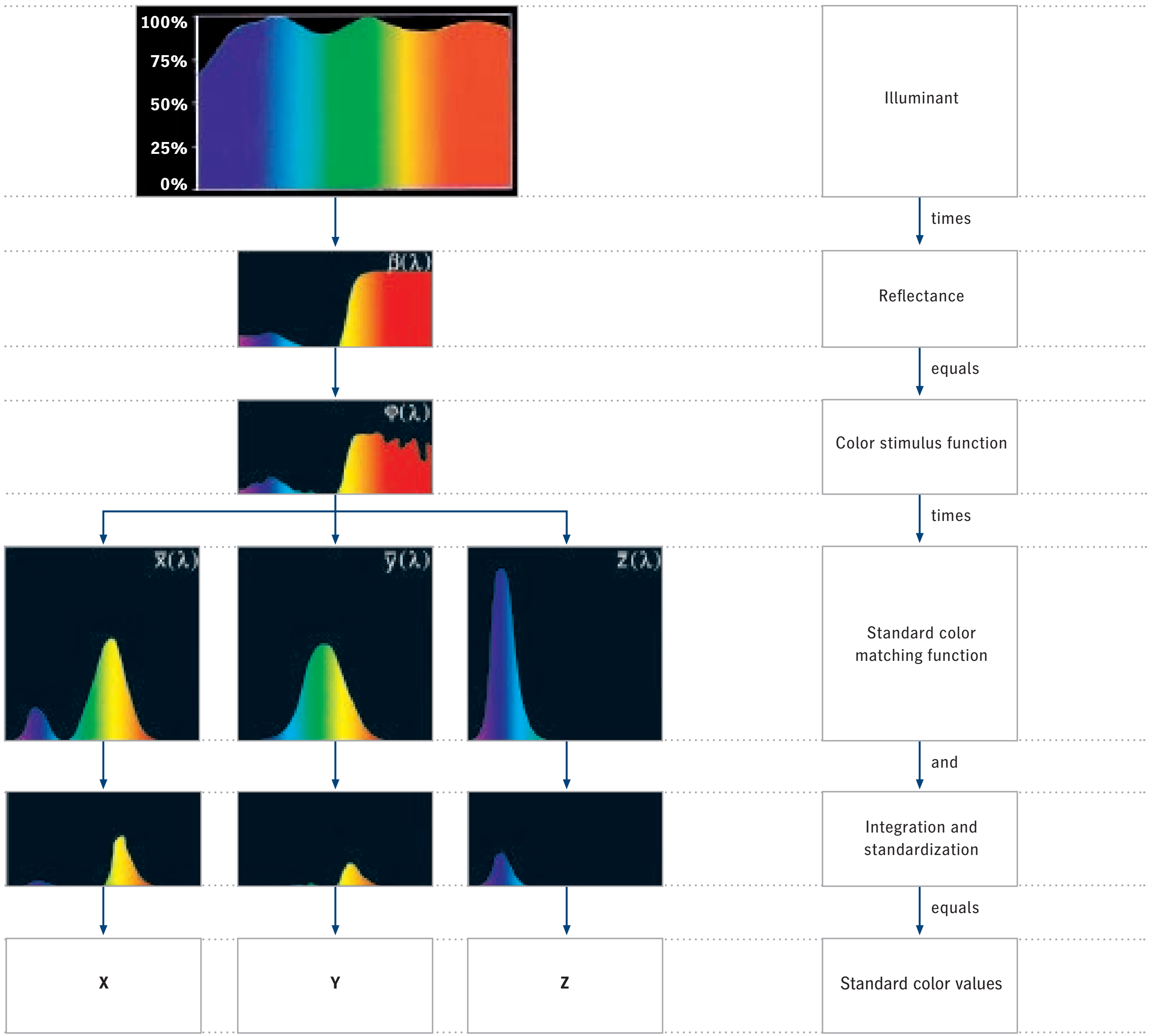
4.5 Evaluation with a spectrophotometer

The standard color values are calculated based on the spectrum of the $S(\lambda)$ illuminant, the measured spectral reflectance of the color $\beta(\lambda)$ and the standardized color matching functions $x(\lambda)$, $\overline{y}(\lambda)$ and $\overline{z}(\lambda)$ for the standard observer.

The lambda in brackets (λ) indicates that the calculation depends on the wavelength λ of the light. The first step is to multiply the radiation function of the standard illuminant $S(\lambda)$ for each wavelength λ (i. e. for each spectral color of an illuminant) by the reflectance values $\beta(\lambda)$ measured for that color. This produces a new curve, the color stimulus function $\psi(\lambda)$.

The second step is to multiply the values of the color stimulus function with those of the standard color matching functions $\overline{x}(\lambda)$, $\overline{y}(\lambda)$ and $\overline{z}(\lambda)$. This produces three new curves.

Finally, integral calculus is applied to determine the areas below these curves, which are then multiplied by a standardization factor to obtain the tristimulus values X, Y and Z, which precisely describe the measured color.



Evaluation with a spectrophotometer

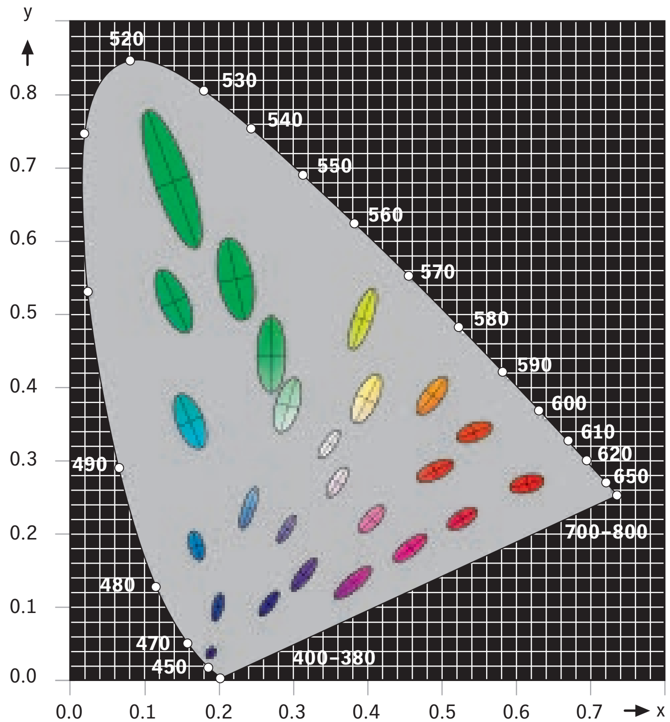
4.6 Equidistant differences in hue

The CIE has already been explained in Section 1.4 on color systems. However, this color space has one major drawback - although the color distances in the chromaticity diagram are numerically the same for each hue, the human eye perceives them to be different.

The American David L. MacAdam explored and quantified this phenomenon in a large number of experiments. The figure shows what are known as the MacAdam ellipses, enlarged by a factor of 10. Since the CIE color space is actually three-dimensional, they are in reality ellipsoids. The size of the ellipsoids represents a measure of the perceptibility threshold for color deviations (seen from the center point of the relevant ellipsoid and for the relevant hue).

As a result, this system cannot be used in practice for evaluating color distances. Using it would mean we would have to accept different tolerances for each individual hue. To reliably calculate meaningful color distances, we need a color space in which the distance between two colors actually corresponds to the perceived distance between them. Two such systems are CIELab and CIELUV, which are derived through mathematical transformation from the CIE color space.

This transformation mapped the MacAdam ellipsoids of different sizes onto spheres almost exactly the same size. As a result, the numerical distances between all colors more or less match the distance between them perceived by the human eye.



xyz color model

4.7. The Lab color model

The problem that our color perception does not tally with reality was solved by the CIE in 1976 with the development of the Lab color model. This is a three-dimensional color space in which color deviations perceived to be equally large also have measurably equal distances between them. This means that each color can be precisely designated using its specific a and b values and its lightness L. The most significant attribute of this color space is, however, as with the standard color system, its device-independency and, therefore, its objectivity.

The CIELab color space is normally depicted as a sphere with three axes. These axes are defined as follows:

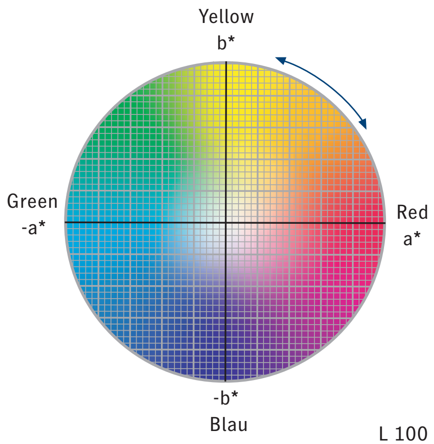
L = lightness axis
a = red-green axis
b = blue-yellow axis

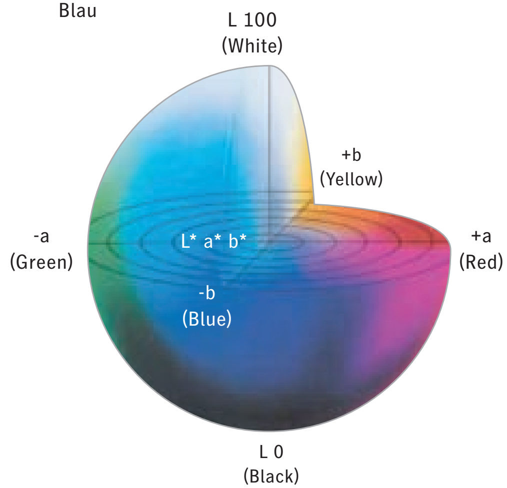
L always lies between 0 and 100, with 0 representing absolute black and 100 absolute white.

The a + b values are at 0 at the center of the axis, i. e. in the area with a completely neutral color. The further away from 0 the a and b values are, the more chromatic/saturated the color.

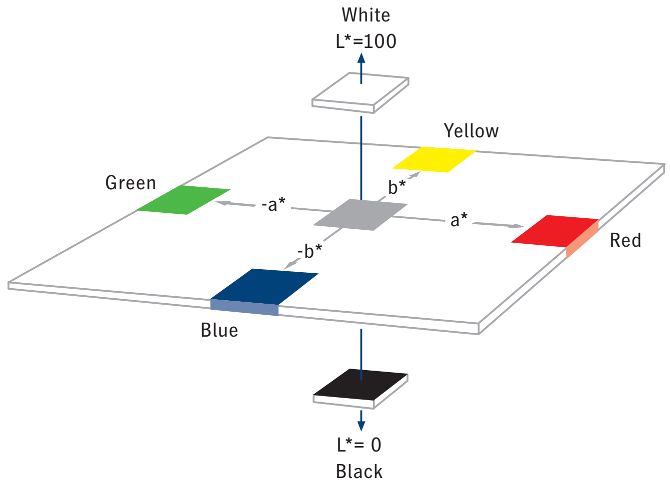
To ensure unambiguous color perception, as far as it is possible with different people, a standard observer and the standard illuminant D50 (5000 Kelvin) were defined. The standard observer views a color sample at an angle of either 10° or 2°. Only the 2° observer is defined for the printing industry. The L*a*b* designation signals that the color values refer to the standard observer's perception.

The colorimetric description of printing inks with CIEL*a*b* values has now become standard. The color coordinates for the process colors cyan, magenta, yellow and black are specified in the ISO 2846 standard. However, this standard only defines the ink itself under specific printing conditions. It is mainly used by ink manufacturers. The color space specified for sheetfed offset printing, on the other hand, is defined by the ISO 12647-2 standard, based on standard inks as defined in ISO 2846-1.0.





The CIE Lab color space



Example	Specified target color	Actual measured color
L*	70.0	75.3
a*	55.0	51.2
b*	54.0	48.4

L* = 75.3 means that the color in question is light and its position of a* = 51.2 and b* = 48.4 locates it between yellow and red. The color in this particular example is, therefore, a light yellowish red or orange.

The actual measured color coordinates deviate from the specified target color.

4.7.1 The CIELab color distance

The difference between two colors is expressed as ΔE in the $L^*a^*b^*$ color space. Δ = Greek for difference, E = English for error. The goal is always to have 1 ΔE correspond to the smallest difference that is perceptible to the human eye. That is why the so-called color distance formulae are constantly being updated and improved.

There are several ΔE formulae that are used to calculate the color distance. Two of them are now widely used in the printing and media industry.

- ΔE (1976), also known as ΔE_{ab} and
- ΔE (2000), also known as ΔE_{00}

Where the distances ΔL^*, Δa^* and Δb^* are weighted equally with ΔE_{ab}, ΔE_{00} takes the hue into account. In this way, the ΔE_{00} formula attempts to eliminate the drawback of ΔE_{ab}, which is that the human eye can hardly perceive 1 ΔE in red, while 1 ΔE in gray is quite easy to see.

The ΔE_{ab} formula is better suited for color control in an offset printing press, because this usually involves strongly saturated, chromatic colors. In other words, these color control systems correct even minimal color deviations, which ensures a very uniform print result.

In Heidelberg color measuring systems, you can choose between the color distances ΔE_{ab} and ΔE_{00} for the display in the basic settings. Regardless of the chosen setting, the recommended follow-up always works on the basis of the ΔE_{ab} formula

$$\Delta E^*_{ab} = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$$

The ΔL^*, Δa^* and Δb^* values represent the differences between the actual and the target value. They correspond to the distances between the color coordinates projected onto the three axes. The following example shows how the color distance between the target and the actual values is calculated.

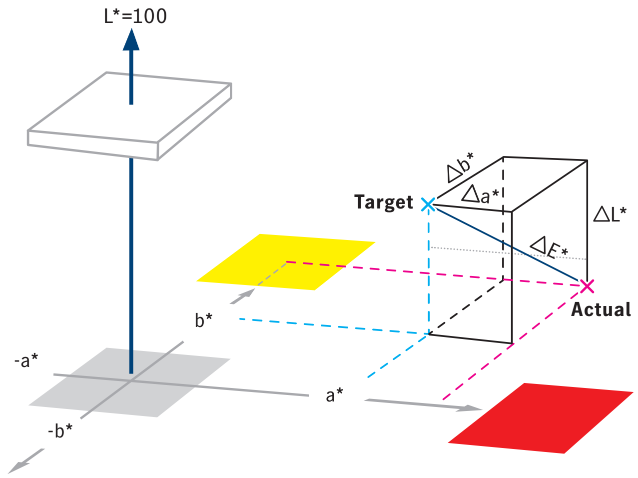
Formula for calculating the color distance based on the ΔE_{00} formula:
This formula includes five correction factors:

- A hue rotation value (RT) that corrects blue hues around 275°
- Compensation for neutral colors
- Compensation for lightness (SL)
- Compensation for saturation (SC)
- Compensation for hue (SH)

Color deviations can be classified as follows in terms of their visibility:

$$\Delta E^*_{00} = \sqrt{\left(\frac{\Delta L'}{S_L}\right)^2 + \left(\frac{\Delta C'}{S_C}\right)^2 + \left(\frac{\Delta H'}{S_H}\right)^2 + R_T \frac{\Delta C'}{S_C}\frac{\Delta H'}{S_H}}$$

ΔE between 0 and 1	Deviation that is not normally noticeable ΔE between 1
ΔE between 1 and 2	Very small deviation; only noticeable to the trained eye
ΔE between 2 and 3,5	Moderate deviation; also noticeable to the untrained eye
ΔE between 3,5 and 5	Obvious deviation
ΔE over 5	Significant deviation



Sample calculation of the color distance between target and actual value:

ΔL^* = 75.3−70.0 = 5.3

Δa^* = 51.2−55.0 = −3.8

Δb^* = 48.4−54.0 = −5.6

$\Delta E^*_{ab} = \sqrt{(5.3)^2+(3.8)^2+(5.6)^2} = 8.6$

Colorimetric values of sheetfed offset inks according to ISO 2846-1

Color	CIELab values			Tolerances			
	L*	a*	b*	ΔE*ab	Δa*	Δb*	L*
Yellow	91.0	−5.1	95.0	4.0	–	–	–
Magenta	50.0	76.0	−3.0	4.0	–	–	–
Cyan	57.0	−39.2	−46.0	4.0	–	–	–
Black	18.0	0.8	0.0	_	1.5	3.0	≤18.0

Colorimetric solid values in sheetfed offset according to ISO 12647-2:2013 for the print run, measured on a white and black backing. CD = Colorant Description

		CD1 (coated paper glossy, matt, semi-matt)						CD 5 (uncoated, wood-free paper – offset paper)					
Coordination		L*		a*		b*		L*		a*		b*	
		Light gray represents the current values, dark gray the desired changes within the framework of the harmonization of the ISO standard and the values of the bvdm's Process Standard Offset. These values also correspond with FOGRA51 and FOGRA52.											
Black	WB	16		0		0		33		1		1	0
	BB	16		0		0		32		1		1	0
Cyan	WB	56		36	-35	-51	-53	60	59	-25	-22	-44	-48
	BB	55		35	-34	-51	-52	58		-24	-22	-44	-47
Magenta	WB	48		75		-4	-5	55		60		-2	-4
	BB	47		73	74	-4	-5	53	54	58		-3	-4
Yellow	WB	89		-4		93	92	89	88	-3		76	
	BB	87		-4		91	90	86		-3		73	70
Red	WB	48		68	69	47	46	53		56		27	26
	BB	46	47	67	68	45		51	52	55		25	
Green	WB	50	49	-65	-66	26	24	53	52	-43	-41	14	11
	BB	49		-63	-65	25	24	52	51	-41		13	11
Blue	WB	25		20	21	-46	-47	39	38	9	10	-30	-32
	BB	24	25	20	21	-45	-47	37	38	9	10	-30	-31
Overprint CMY100	WB	23		0	-1	-1	-2	35		0	1	-3	-4
	BB	23		0	-1	-1	-2	34		0	1	-3	-4

WB = White Backing BB = Black Backing

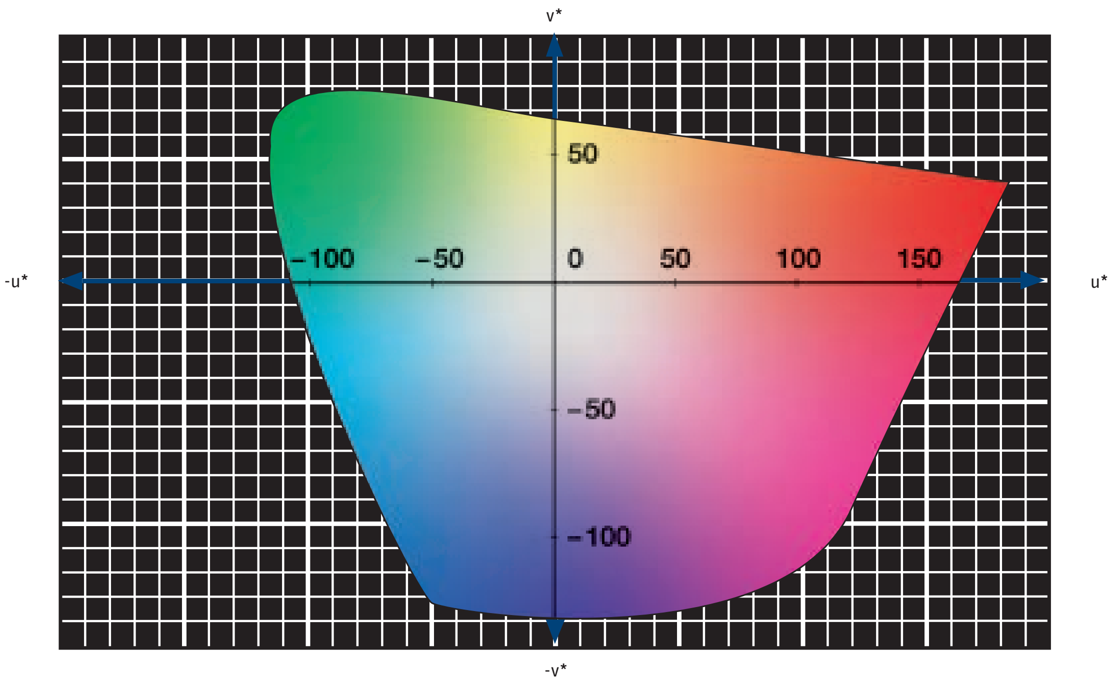
4.7.2 CIELUV

The CIELUV color space is also derived through transformation from the CIE color space. The three coordinate axes are designated L*, u* and v*.

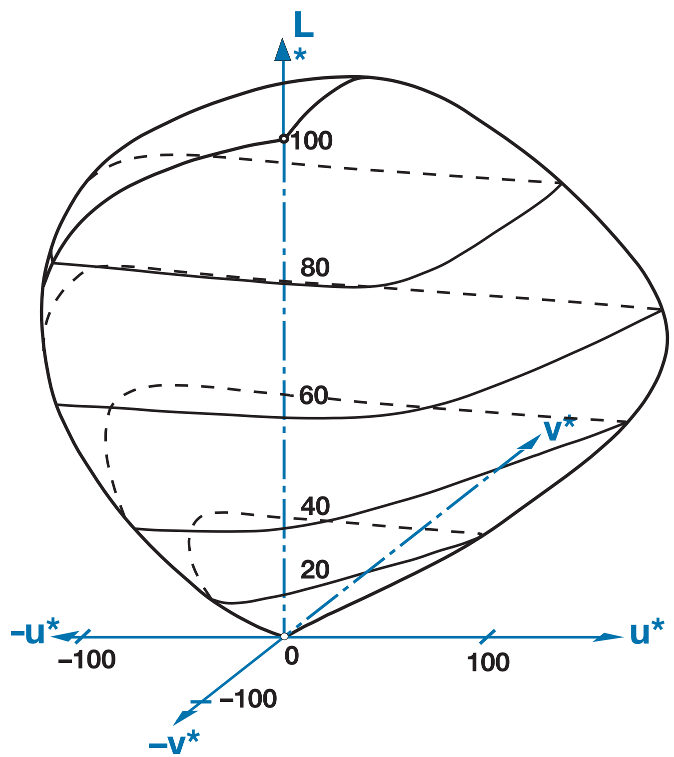
Since the CIELUV and CIELab color spaces are the result of different transformations, they also differ in shape. Both are used to map non-luminous colors.

The figure shows a cross-section of the CIELUV color space for non-luminous colors with a lightness value of L* = 50. The green colors are located further inward than in the CIELab color space, and the blue range is larger.

The CIELUV color space is often used to assess the display colors in color monitors (e. g. television screens or computer monitors). Its advantage is that it is derived by a linear transformation, which means that the color relationships are the same as in the CIE color space (this is not the case with the CIELab color space).



Cross-section of the CIELUV color space for non-luminous colors.



4.7.3 CIELCH

CIELCH is the designation used if, instead of the Cartesian coordinates a*, b* and/or u*, v*, the cylindrical coordinates c (chroma, as distance from the center) and h (hue = angle) are used in the CIELab or CIELUV color spaces. In other words, it is not a color space in its own right.

The calculations involved correspond to those in CIELUV.

CIELCH

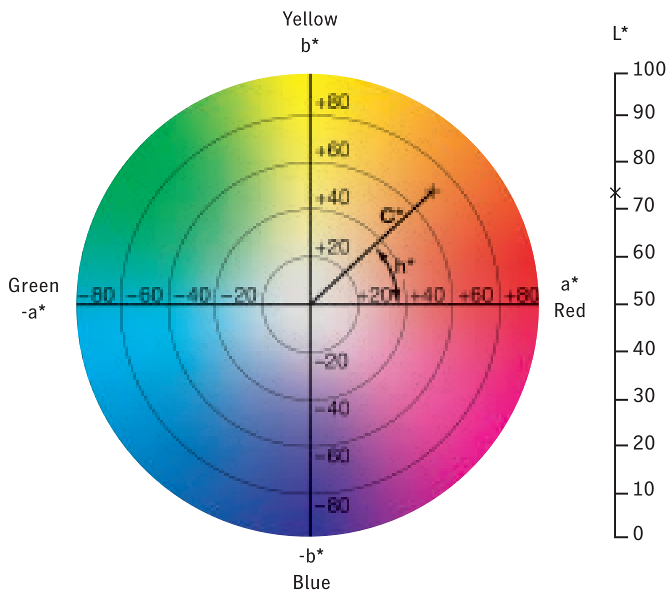
Actual color:	$L^* = 75.3$
	$C^* = 70.5$
	$h^* = 43.4°$

CIELUV

The lightness L^* remains unchanged.

The chroma C^*_{ab} is calculated with $C^*_{ab} = \sqrt{a^{*2} + b^{*2}}$.

The hue angle h^*_{ab} is calculated from $h^*_{ab} = \arctan\left(\frac{b^*}{a^*}\right)$.



4.7.4 CMC

CMC, a system for evaluating color distances based on the CIELab color space, was developed in Britain in 1988 by the Colour Measurement Committee of the Society of Dyers and Colourists (CMC). Unlike CIELab or CIELUV, it does not describe how differences in colors are perceived, but how well they are accepted by an observer.

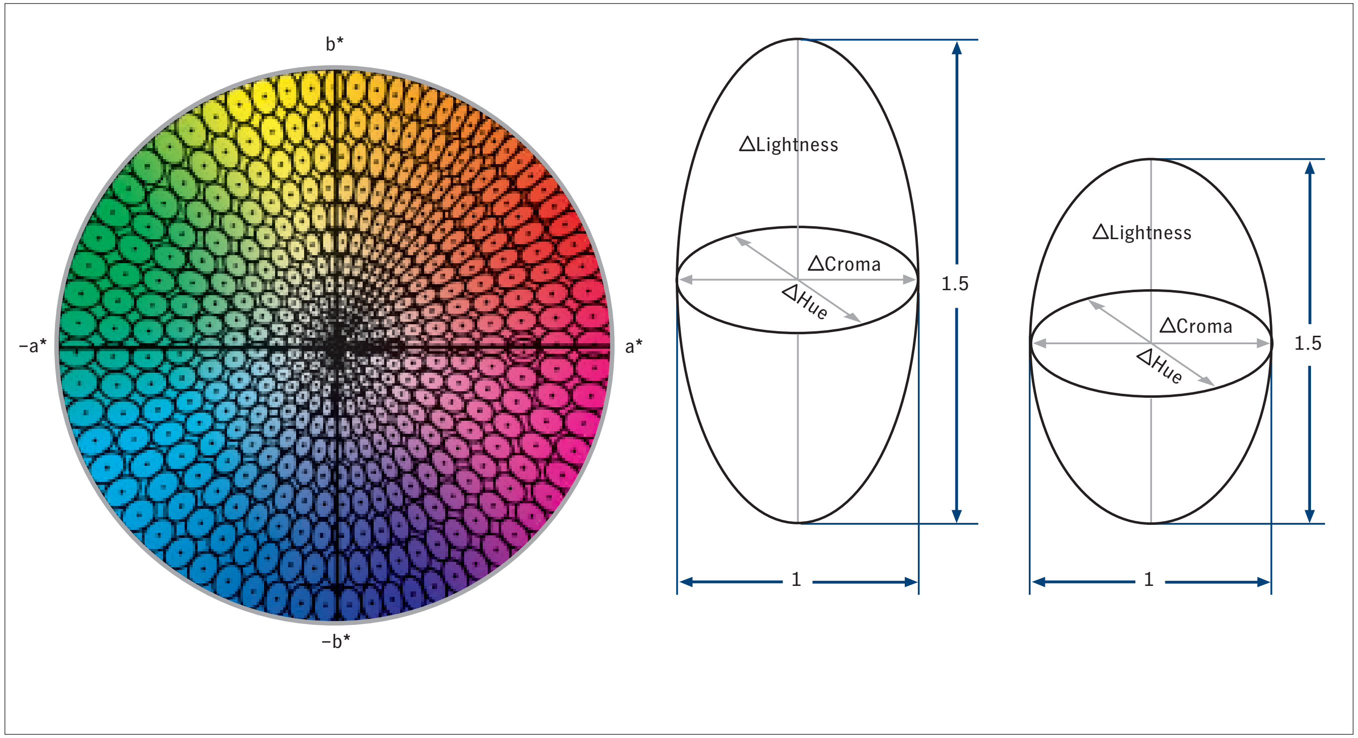
It addresses the fact that, generally speaking, color fluctuations near the lightness axis are perceived as much more irritating than deviations in more saturated colors. Similarly, fluctuations in chroma (saturation) are much more readily accepted than fluctuations in the hue angle.

The figure on page 46 illustrates the application of the CMC principle to assess color distances in the CIELab color space Each ellipse shows colors with constant distances around the target locus based on the CMC equation.

As can be clearly seen, the ellipses (representing tolerances in the CMC color space) are smaller in the achromatic area than in areas with greater saturation. They are also shaped so that the permissible deviations in hue angle are smaller than those in the chroma value. They also allow for flexible adjustments for assessing lightness and color deviations. These adjustments are made using two weighting factors, l and c (where l is the weighting factor for lightness, and c is the weighting factor for chroma, which is normally 1).

The textile industry often uses weighting factors with a ratio of l : c = 2 : 1. This means lightness deviations are twice as likely to be accepted as color deviations.

This ratio can be adjusted to suit each application. As a result, however, the color distance values are only informative and comparable in conjunction with the same weighting factors.



CMC color space model

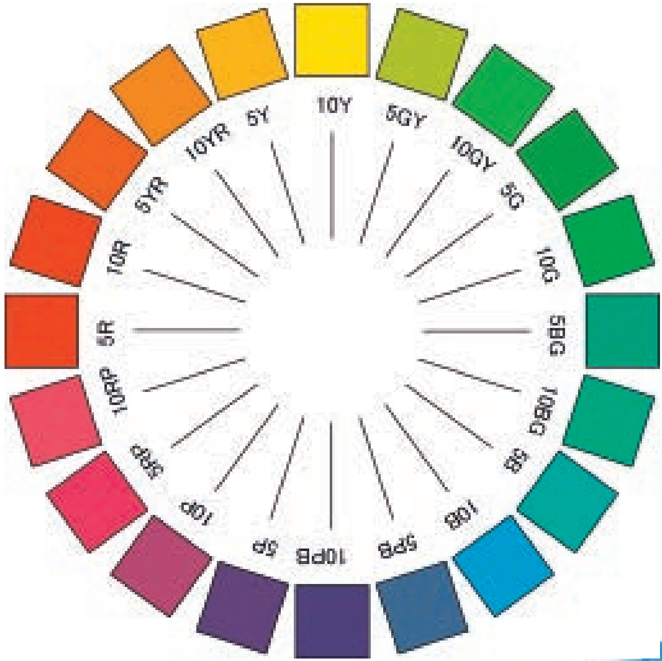
4.8 Munsell

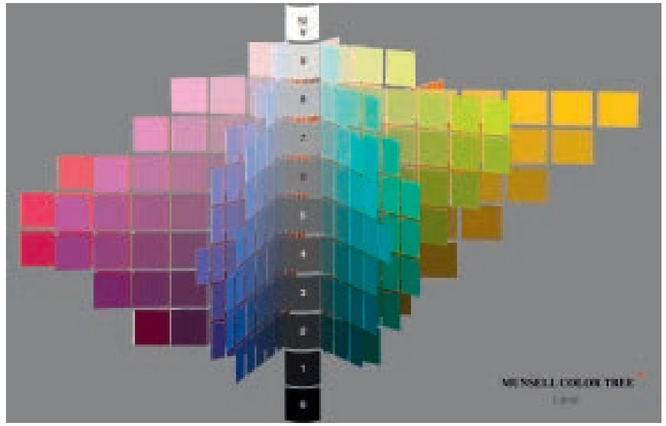
In 1905, Alfred Munsell developed a color system that represents color distances as they are perceived. He used the terms hue, value (lightness) and chroma (saturation) to describe the attributes of a color. Five basic hues make up the notation system – red, yellow, green, blue and purple. The system was published in 1915 as the “Munsell Book of Color” for 40 hues with the C illuminant, including both glossy and matt samples.

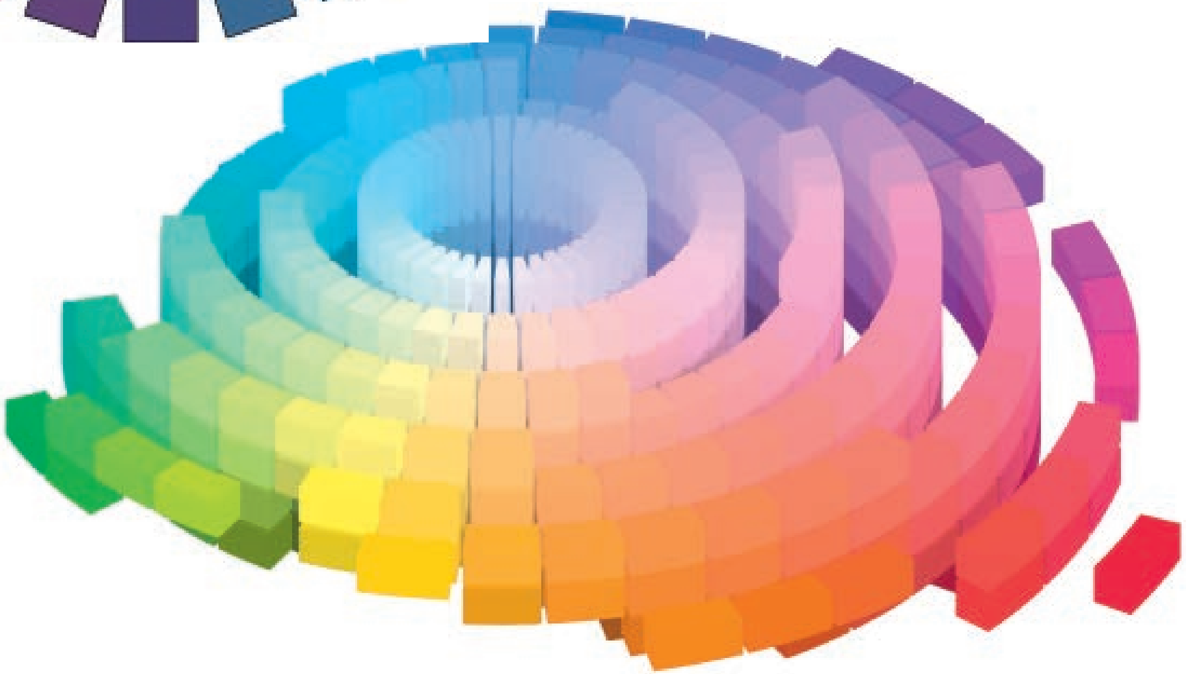
Each of the five principal hues is subdivided into as many as 100 even-numbered hues, each of which has a grid comprising 16 chroma and 10 lightness levels. The figure shows a cross-section of the Munsell color tree with 40 hues. Not all of the slots in each grid are occupied, resulting in an irregular color space.

Munsell coordinates cannot be mathematically converted into CIE coordinates.

Other color systems include the DIN Color Atlas (DIN6164), the Natural Color System (NCS), the OSA system (from the Optical Society of America) and the RAL Design System (RAL-DS).







5 Colorimetry Applications.

5.1 Spectrophotometry

Spectrophotometry measures the visible spectrum, for instance, from 380 to 730 nanometers. The light reflected by an ink is split into its spectral components using a diffraction grid or other technologies, and these are captured by a large number of sensors.

The measured remission values are used to calculate the standard color values X, Y and Z. This is carried out on a processor using the standard color matching functions x, y and z. Since these functions do not need to be modeled with glass filters, a spectrophotometer's absolute precision is very high.

A major advantage of spectrophotometry – besides its high absolute precision – is the fact that spectrophotometers can output the standard color values for all standardized illuminants and observers, provided the corresponding values have been stored. They can also calculate densities for any filter standard.

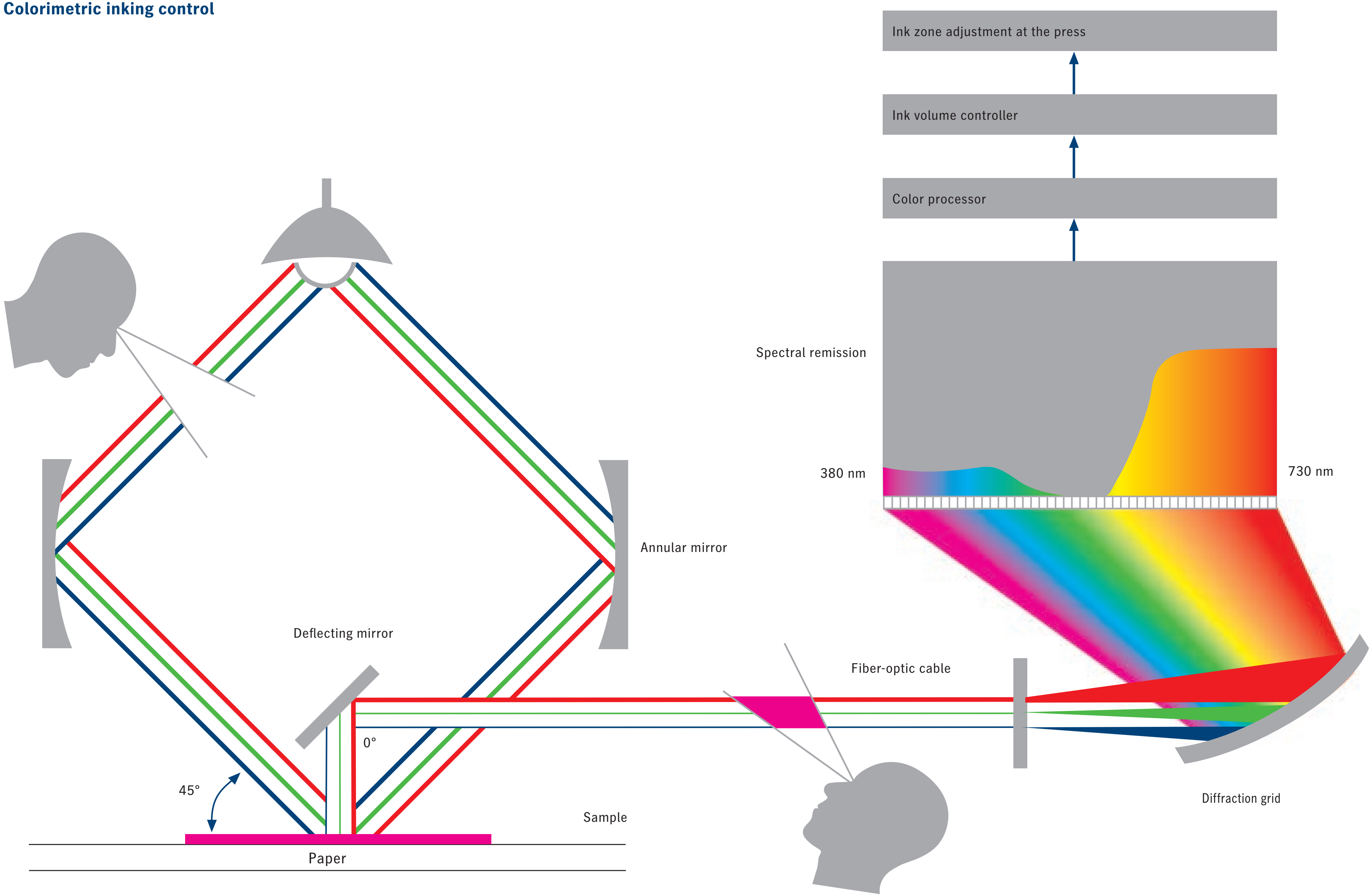
Ink manufacturers are required to comply with precise specifications when making their products. This is very important for standardized colors (ISO 2846-1), but also for HKS and all special color mixes. They achieve this by measuring a sample with a spectrophotometer and then using an appropriate formulation program to calculate the proportions for mixing the ink.

The operating principle of a spectrophotometer is shown in the diagram on the right.

First, the light is directed onto the printed sample at an angle of 45°. The light reflected at an angle of 0° is relayed from the measuring head to the spectrophotometer via a deflecting mirror and a fiber optic cable. There, it is split into its spectral colors by a diffraction grid (in a similar way to a prism).

Photodiodes then measure the radiation distribution across the entire visible spectrum (between 380 and 730 nanometers) and forward the results to a processor. This processor colorimetrically evaluates the measured values and outputs them as Lab values. Once the measured values have been compared with the previously entered target values, the system calculates the recommended relative adjustments for the various colors and transmits these recommendations to the press control system. The control system converts the data into absolute values for controlling the individual ink zones and passes them on to the ink zone motors.

Colorimetric inking control



5.2 Print control strips

Heidelberg also markets a library of digital print control elements (Dipco – digital print control elements) for all color-related Prinect products. This comprehensive package includes all the digital elements needed to check and control the results obtained at each stage of the printing process, from prepress through to printing. Which print control strips are used depends primarily on the colors required for the job. All relevant strips are stored in the Prinect color measuring systems. They are either selected manually by the press operator or automatically in the Prinect color workflow. Prinect Inpress Control automatically identifies the type and position of the print control strip on the sheet using synchronization marks. The results from measuring every element of the print control strip are compared with the stored reference values of the color measuring systems. Based on this comparison, the Prinect color measuring systems then calculate recommended adjustments for the individual ink zones in each printing unit.

Tips on how to position print control strips:

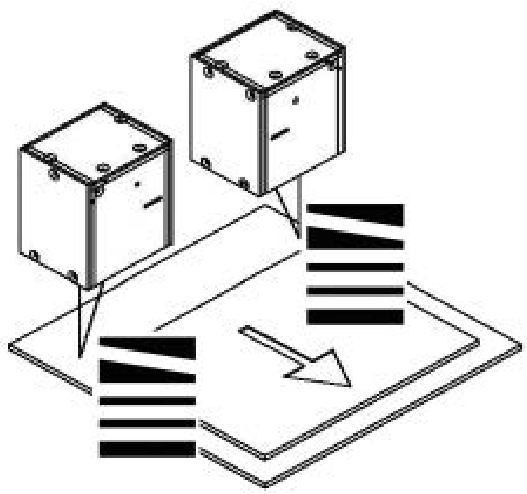
- Do not place the strip diagonally on the sheet, but parallel to the sheet edge
- Always select the print control strip that is suitable for the specific press and position the strip so that its center is at the center of the press, even if the paper is offset from the press center
- Position all parts of the strip together in one row without separating them
- Select the correct strip for the print job
- (only process colors, process colors with spot colors, only spot colors)
- Select the correct strip for subsequent measurement and control with color measuring systems
  – solids/gray patch control
  – solids control only
- Select the correct strip for the halftone patches you want to evaluate
- For a standard-compliant measurement of tonal values and better adaptation of the characteristic curve, always use strips with halftone patches in the mid-tone and three-quarter tone range, e. g. 40 % and 80 % or 50 %
- and 75 %
- Do not decrease, increase or crop the print control strip's height or width
- Position the strips so they are not in the gripper area
- Strips can be placed at the lead edge, the tail edge or in the middle of the sheet (perfecting)
- When working with Prinect color measuring systems, always adhere to the Dipco positioning guidelines. Take the software status of the measuring device and the Dipco control elements into account

Never crop the measurement patches to the left and the right! If possible, always leave a margin of 1 mm paper white between the print control strip's patches and the printed image, as well as the paper and gripper edges.

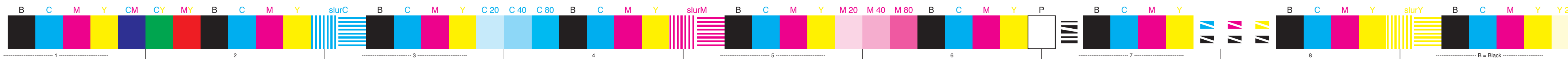
When working with Prinect Easy Control®, Prinect Axis Control® and Prinect Image Control®, leave 5 mm of paper white to the left and right of the print control strip.

With Prinect Inpress Control, always make sure the synchronization marks are located in the printable area! In addition, there should always be a margin of 1 mm paper white between the strip's patches and the printed image, as well as the gripper edges.

The individual patches in the print control strips are either 4 mm or 6 mm high and 3.25 mm or 5 mm wide. The ink zones are 32.5 mm wide on all Speedmaster® presses, which means there is room for either 13 or 20 patches across two ink zones.



Special sensors in the Prinect Inpress Control register measuring head automatically detect the print control strip.



5.3 Color control with Heidelberg

5.3.1 Color measuring systems from Heidelberg

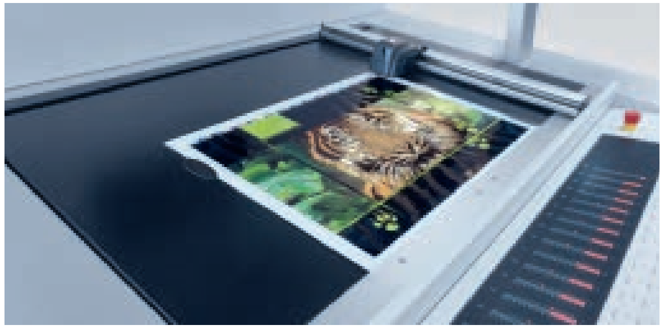
Heidelberg only markets systems based on spectral measurement and colorimetric control. After the operator has approved the color deviations measured, they are forwarded online to the press control console and converted into ink zone adjustments. In Prinect Inpress Control, adjustments can also be carried out fully automatically immediately after each measurement.

All devices can measure and display solids, halftones, slurring and doubling in the print control strip. All required print control strips can be downloaded free of charge from the Heidelberg website – www.heidelberg.com – simply search for “Dipco”.

All Prinect color measurement devices come with an integrated color database with Pantone and HKS $L^*a^*b^*$ values.

Prinect Easy Control

Prinect Easy Control is a semi-automatic color measuring device integrated into the press control console. Its easy-to-operate concept makes it an ideal gateway for newcomers to spectral measurement technology.



Prinect Easy Control

Prinect Axis Control

Prinect Axis control is a measuring device integrated into the press control console with motorized measurement head movement in the X and Y directions. Vacuum suction holds the sheet absolutely flat, even with high grammages.

Prinect Image Control

Prinect Image Control is a standalone measuring device for connection to up to four Heidelberg printing presses. Vacuum suction holds the sheet absolutely flat, even with high grammages. The device is operated via its own touchscreen monitor. Prinect Image Control measures and controls color in the entire print image, and controls opaque white in the print control strip.

By accepting CIP4-PPF data from prepress, it offers the following options:

- Adjustment of prints to match a proof
- Color management, Mini Spot workflow, process control
- Sheet inspection for printing errors
- Special applications for security and rainbow printing

Prinect Inpress Control

Prinect Inpress Control is a measuring device that is integrated into the press. It automatically detects the print control strip and can measure at all press speeds. It comes with an additional hand-held spectrophotometer for measuring paper white and color samples.

Prinect Axis Control

Prinect Image Control

Prinect Inpress Control

5.3.2 Colorimetric control methods

Heidelberg color measuring systems measure spectrally and control colorimetrically. They can be operated with a choice of two different types of color control modes:

- colorimetrically based on solid patches in a print control strip (for CMYK and spot colors)
- colorimetrically based on overprinted patches that have been autotypically screened.

The latter variation was originally intended only for measuring and controlling in a gray patch made up of the process colors CMY. With today's modern gray balance optimization based on tonal value adjustment during printing plate exposition, this form of control using gray patches has been pushed more into the background.

Heidelberg devices now measure the entire print image, instead of just the overprinted patches. Prinect Image Control is the first and only device worldwide to spectrally scan the printed image and control the ink zones on the basis of the digital image data. This means that what you measure is what you sell to the customer later on. Naturally, gray tones can be precisely measured and controlled just as well as colored image areas.

All control modes use colorimetric reference values. This ensures a perfect color match between the print result and the reference values, which is paramount. The colorimetric approach used in Heidelberg color measuring systems ensures that perceived color differences between the OK sheet and the print run sheet are optimally controlled and minimized by a technology that emulates the functioning and color perception of the human eye.

5.3.3 Prerequisites for measuring and controlling at the press

Before taking a look at how different measuring systems work, we need to define the most important prerequisites for reliable measurement and control.

Color presetting and preinking are the number one concerns. Color presetting is mainly governed by the area coverage values of the print form, i.e. the subject, as well as by the ink and substrate parameters (characteristic curves stored in the press). Ideally, area coverage values are determined using CIP4-PPF data from prepress that have either been transmitted to the press online or supplied via a storage medium. The objective of color presetting is to ensure that inking is as close as possible to the required target values immediately the press starts printing. The ink zone openings in every zone and the ink stripe widths (fountain roller sweep) in every inking unit are set according to the estimated ink consumption. To set the ink zone openings, the characteristic curves are applied to convert the area coverage values into color presetting values.

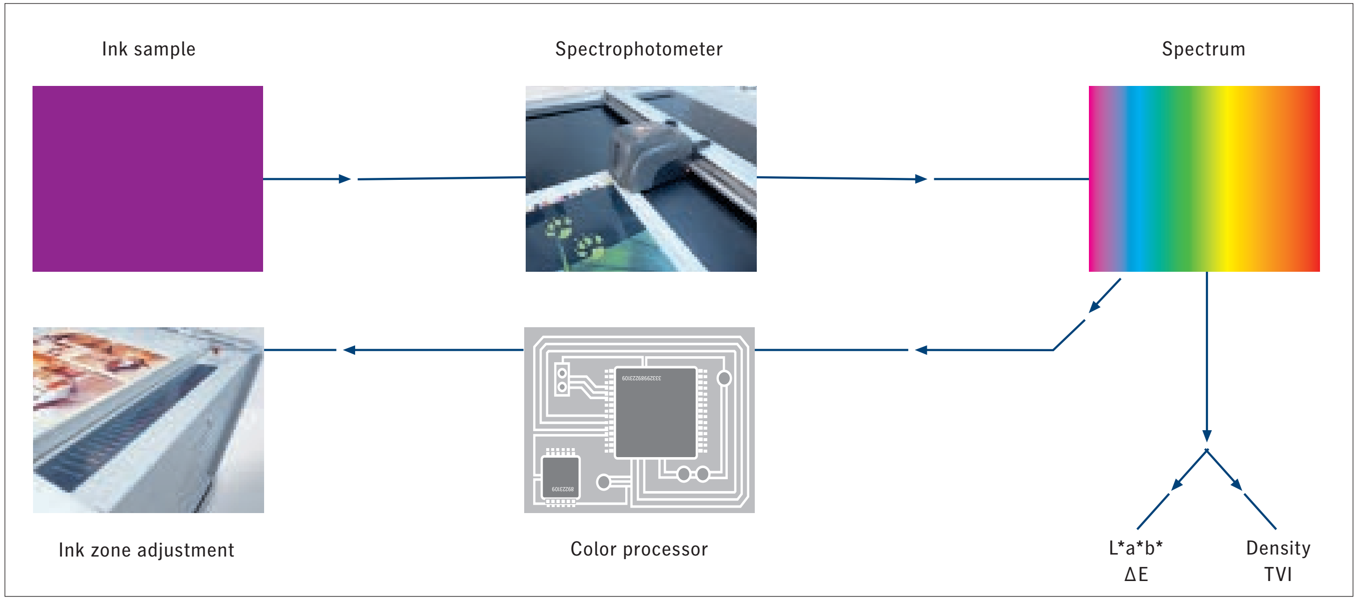
A frequently underestimated factor is so-called preinking. Before the first sheet is printed, the amount of ink required later on during the print run under stable printing conditions is fed into the inking unit. The rule here is: if inking is set up well at the onset, there is no need to adjust it subsequently. Carrying out the steps described above for ink presetting ensures that when printing begins inking is close enough to target to start color measurement and control.

5.3.4 How Heidelberg color measuring systems work

Heidelberg uses spectrophotometers for all its color measuring systems, no matter whether they output ink densities or L*a*b* values. The spectra measured are forwarded to an integrated processor, where they are used to calculate the required values. These color values are the basis for colorimetric control. In other words, the recommended adjustments for the ink zone openings are calculated directly using a color model that defines the color change resulting from a change in the ink film thickness.

For control purposes, it is vital that the spectral values are stored in the measuring device as reference values. The reference values for Pantone and HKS spot colors are stored in Prinect color measurement systems and in the Central Color Database of the Prinect Production Manager at the factory.

No spectral values are stored for process inks (4C), highly pigmented inks or other miscellaneous inks. There are two reasons for this – the large number of ink types used in practice, and the fact that the colors of process inks often vary considerably. This makes it necessary for the press operator to determine the spectral values of these inks by measuring a print sample (solids) to ascertain the new reference color coordinates. This only takes a few minutes and has the advantage of generating reference values that can realistically be achieved with the ink used in the print shop. Quality control can also be carried out by monitoring color deviations, for instance between different batches of ink.



How Heidelberg color measuring systems work.

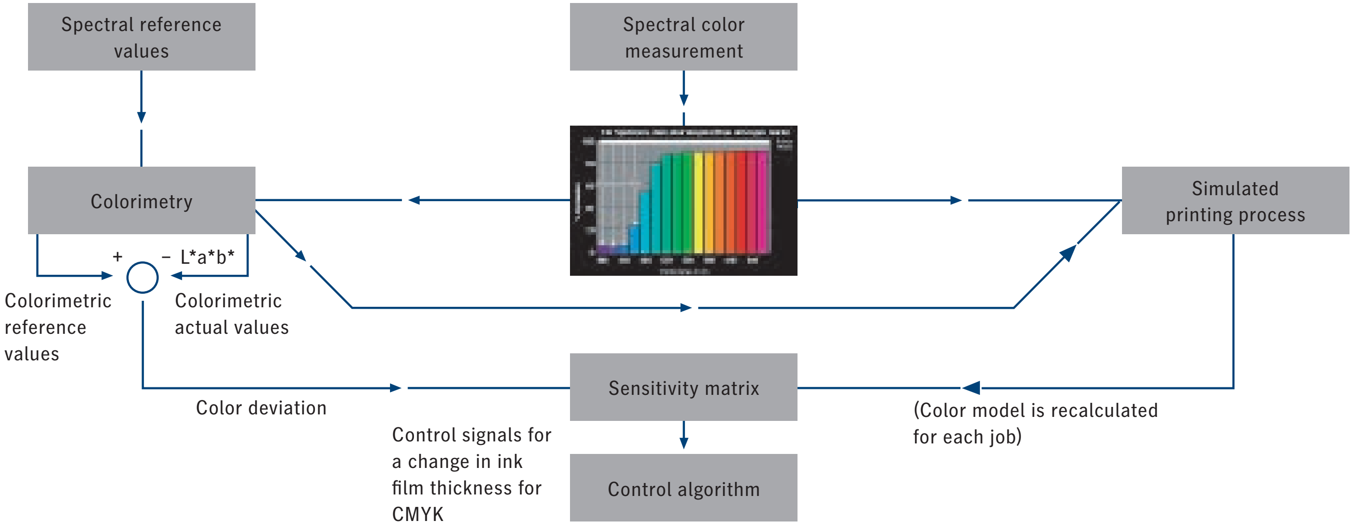
5.3.5 Determining reference values – a practical example

A print shop wants to print according to the ISO 12647-2 standard. This standard defines dot gain as well as the colorimetric reference values expressed as CIE L*a*b* coordinates that ensure a true-to-color print. Due to the influence of various factors, the CIE L*a*b* values can never be perfectly matched, which is why tolerances are also specified for the individual process colors and for the print run. It is important for the press operator to know how closely he can approximate the reference values with the inks he is using.

There are two practical approaches for determining the achievable target value (= print run standard).

1. Print a series of sheets with inking ranging from underinking to overinking and then measure them. The sheet that has the lowest ΔE deviation from the target value within the permissible tolerances may be used as the standard for the measuring system.
2. Ask the ink manufacturer to perform a laboratory test print on the same paper that will be used for the job. Scan this print with the measuring system and define it as the standard.

Translating color deviations into recommended adjustments for ink zones and controlling color during the print run



5.3.6 Color measurement and control during the print run

Once the target values have been determined, measurement of the print run can begin. The first actual measured values come from the first pulled sheet. These initial values should be relatively close to the target values. The objective now is to adjust the ink zones, and thereby the ink film thickness, to achieve the target values as quickly as possible.

At first sight, this approach may seem simple, but it is based on a complex color model that describes how changes in the ink film thickness affect the color of the ink used. Colorimetry by itself can only tell us where the color achieved so far is located in the color space (actual measured value) and where it needs to be (target or reference value). It cannot tell us how to accomplish this, since this is the color model's job, not colorimetry's. The color model can be used to work out how the color changes if, for example, the ink film thickness is increased by 5 %. If the ink film thickness on the paper is changed, its visual appearance naturally also changes. Imagine the color coordinates for a series of prints ranging from very low inking to full saturation within the CIE L*a*b* color space. These coordinates fall along a line that varies not only in lightness but also in its position on the a and b planes. This is called a color line. When solids are controlled, the achievable color coordinates are governed by the ink's pigmentation and the paper used. The color model can be used to calculate which ink film thickness comes closest to producing the target value and where the target value is located within the color space.

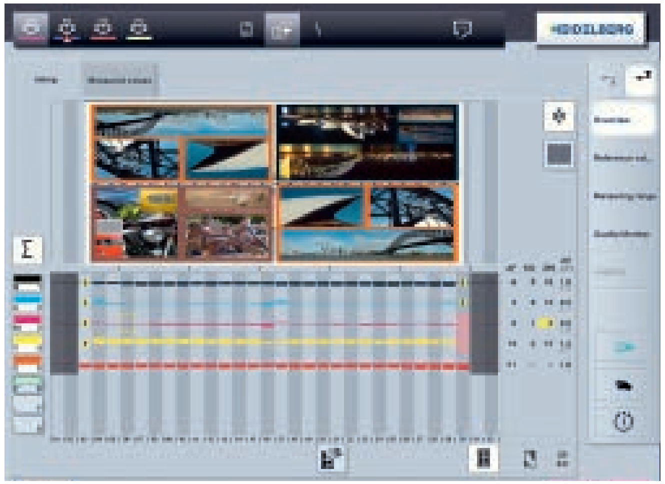
5.3.7 How colorimetry can help

In practice, this means that the press operator can see at a glance whether he can achieve the required color results. If all the parameters in the print process are optimally coordinated, he can expect to achieve them. If the printing conditions change, for instance due to blackening of the chromatic colors during the print run, the colors can deviate significantly from the targets. In this case, colorimetry can be a great help in indicating whether the required color results can still be achieved within the specified tolerances, or whether it is necessary to take any action such as washing the inking rollers. When using a different type of ink, the color measuring system also shows right from the very first pull whether or not the achievable color is within the tolerance. Working with a different make or type of ink and a previously stored reference value can lead to colors outside the tolerances. Different batches of the same type of ink may also enable you to achieve the same CIE L*a*b* values, but with different densities. If the sheet was only printed according to the reference densities, the visual appearance of the prints might be subsequently different. This is one reason why the ISO standard does not specify any reference densities.

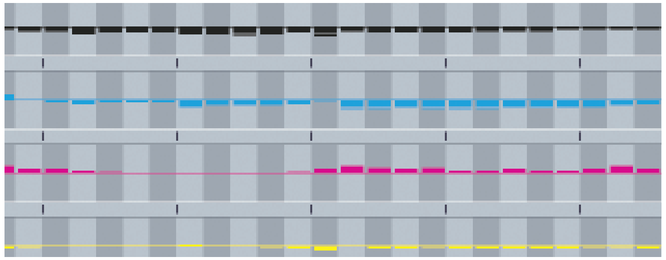
5.3.8 Summary

The great advantage of colorimetric control is that it allows the press operator to achieve printing results that are as close as possible to the actual appearance of the original. Colorimetric control always shows the results for two types of measurement: ΔE can be adjusted and is the difference between the measured value and the best possible match with the actual ink and paper. ΔE_0 cannot be adjusted and is the difference between the best match and the reference value stored in the system. Colorimetric evaluation corresponds to the color perceptions of the human eye, with the additional advantage of being free from subjective influences and variable environmental influences; that is why it can deliver objective readings. The measurement data can be stored and documented for use in quality certificates. Measurement results can also be automatically evaluated using the Heidelberg Quality Monitor.

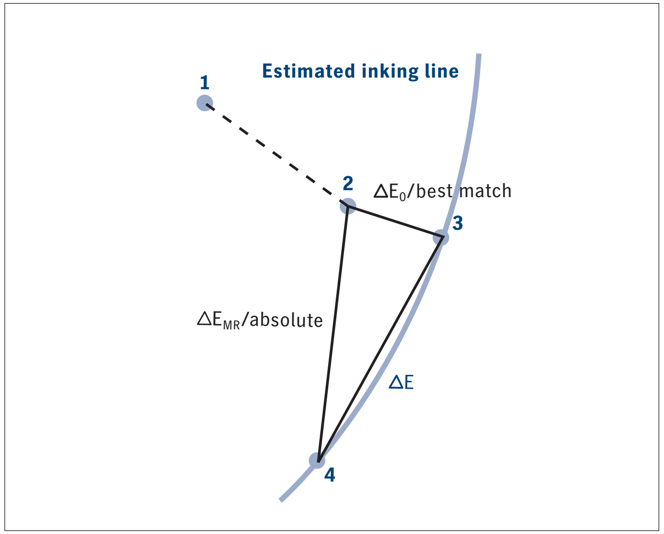
Information displayed by Prinect Image Control during a measurement



The press operator sees at a glance where inking needs to be corrected.



The lines show the reference colors.
The bars show the underinking and overinking for each ink zone.



Example of a color line in the CIELab color space.

5.4 Standardization in printing

Standardization in the graphic arts industry is based on the following standards.

5.4.1 Printing inks conforming to ISO 2846-1

The Euroscale, originally defined by DIN 16539 in 1975, has evolved further. In 1996, ISO 2846 succeeded in establishing a common process standard that incorporated the ideas of the U.S. SWOP and the Japanese TOYO standards. Part 1 of this standard defines tolerances for colorimetric properties and transparencies for process inks in four-color sheetfed and web offset printing that must be achieved when making proof prints on APCO paper with a defined reference ink film thickness.

However, the color values specified in this standard are binding only for ink manufacturers, not for print shops.

5.4.2 ISO 12647-2 and the Process Standard Offset (PSO)

In 1981, the German Printing and Media Industries Federation (bvdm) issued its first publication on standardizing sheetfed offset printing. Practical experience and the relevant scientific research findings made subsequently were incorporated into the international standard ISO 12647-2 “Process control for the production of halftone separations, proof and production prints – offset lithographic processes”. ISO 12647-2 is regularly revised to incorporate new findings and process technologies. The following relates to the version in force when this brochure went to press – ISO 12647-2:2013. In 2003, the German Printing and Media Industries Federation (bvdm) joined forces with FOGRA to produce the Process Standard Offset (PSO), the first procedure for complying with and checking standards to ISO 12647-2. The current edition was released in 2016 and can be ordered in printed form from bvdm. In addition to the specifications in the ISO standard, the PSO contains further recommendations and control tools. The best known of these are the FOGRA media wedge for proof quality control and the FOGRA print control strips. However, the PSO itself is not a standard.

5.4.3 The MediaStandard Print

In 1997, the bvdm first introduced the MediaStandard Print. In addition to the technical guidelines for digital printing data that are based on ISO 12647, this standard defines the specifications and tolerances for digital contact proofs. This gives agencies, prepress departments and print shops a body of rules that forms the basis of an improved communication and optimized workflow. The current version of the MediaStandard Print can be downloaded free of charge at
https://www.bvdm-online.de/fileadmin/tundf/bvdm_Medienstandard_Druck_2016.pdf
Primarily, it defines the following conditions:

- The proof must simulate one of the reference printing conditions characterized in the PSO.
- The proof must contain a comment line showing the file name, output date and the color management settings used.
- There must be a UGRA/FOGRA media wedge.
- Measurement conditions are specified for the evaluation.

Process Standard Offset of the German Printing and Media Industries Federation (bvdm), prepress parameters for sheetfed offset printing

Screen ruling	58 L/cm to 80 L/cm					
Screen angle	Nominal angular difference between C, M, K = 60° (chain dots), = 30° (circular or square dots) Y = 15° from another color, dominant color at 45° or 135°					
Halftone dot shape	Print control strip: circular dot, image: chain dot with 1. dot touch ≥ 40 %, 2. dot touch ≤ 60 %					
Total area coverage	≤ 330 %					
Gray balance	Non-binding gray balance values according to ISO 12647-2:2013 that can offer orientation if no ICC standard profiles are used.					
	Cyan	Magenta	Yellow	L*	a*	b*
Quarter tones	25.0 %	18,4 %	18,6 %	75,6	0,8	– 3,1
Mid-tones	50.0 %	40,9 %	40,1 %	56,7	0,5	– 2,2
Three-quarter tones	75,0 %	68,9 %	69,9 %	39,0	0,3	– 1,4

Reference dot gain for the two paper types

Halftone patches (%)	**Dot gain (%) with tolerances for paper grades 1 + 5**	
Tone value of control patch	**Deviation tolerance OK sheet–ISO value**	**Deviation tolerance production print–OK sheet**
< 30	3	3
30 to 60	4	4
> 60	3	3
Maximum mid-tone spread	5	5

MediaStandard Print 2016, CIEL*a*b* color values of the solid base colors for sheetfed, web and continuous offset on eight paper grades

Paper category	NEW – being introduced						OLD – will gradually be replaced by NEW						NEW – 2016–2018 being checked by ECI WOWG (OLD therefore valid for time being)															not currently valid		
	1 (replaces old 1/2)			5+ (replaces old 4; old 5 lapses			1/2 (will be replaced by new 1)			4 (will be replaced by new 5+)			2 (old LWC-I)			3 (old LWC-S)			4 (old MFC)			6 (old SC)			7 (old INP)			8 (SNP heatset)		
g/m² range	80 … 250, approx.115			70 … 250, approx. 120			approx. 115			approx. 115			51 … 80, approx. 70			84 … 70, approx. 51			51 … 65, approx. 54			38 … 60, approx. 56			40 … 56, approx. 49			40 … 52, approx. 45		
Gloss below 75°	35 … 70			5 … 15			approx. 65 (1)/ 38 (2)			approx. 6			25 … 65, approx. 55			60 … 80, approx. 55			7 … 35, approx. 21			30 … 55, approx. 43			10 … 35, approx. 21			5 … 10		
CIE Whiteness	105 … 136			140 … 175			105 … 136			140 … 175			90 … 105			60 … 90			75 … 90			45 … 85			40 … 80			35 … 60		
Solid inking on white backing (wb) – for measurement on proofs as well as test forms for producing characterization data or profiles for proof and production printing conditions																														
Color values	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
Black (K)	16	0	0	33	1	0	16	0	0	31	1	1	20	1	2	20	1	2	24	1	2	22	1	3	32	1	3	Not supported by the Process Standard Offset due to intentional deviation in measuring on black backing in the characterization data!		
Cyan (C)	56	-35	-53	59	-22	-48	55	-37	-50	60	-26	-44	57	-37	-46	56	-37	-42	55	-33	-42	55	-36	-38	58	-29	-36			
Magenta (M)	48	75	-5	55	60	-4	48	74	-3	56	61	-1	48	73	-6	47	71	-4	49	67	-2	48	66	-3	52	58	-2			
Yellow (Y)	89	-4	92	88	-3	72	89	-5	93	89	-4	78	86	-2	89	84	-1	88	84	-2	81	83	-1	86	82	-1	72			
Red (M +Y)	48	69	46	53	56	26	47	68	48	54	55	26	48	66	44	47	65	44	48	62	39	47	62	40	50	56	30			
Green (C+Y)	49	-66	24	52	-41	11	50	-65	27	54	-44	14	50	-59	26	50	-56	28	50	-52	24	49	-53	25	52	-43	17			
Blue (C+M)	25	21	-47	38	10	-32	24	22	-46	38	8	-31	28	16	-46	28	15	-42	28	17	-38	28	13	-39	37	8	-31			
C + M + Y	23	-1	-2	35	1	-4	23	0	0	33	0	0	27	-4	-2	27	-2	0	28	2	-3	27	-1	-3	34	-3	-5			
Paper tone	95	1	-6	94	2	-10	95	0	-2	95	0	-2	92	0	-2	90	0	1	90	0	0	89	0	5	88	0	2			
Solid inking on black backing (bb) – only for measurements of production prints, reference print specimens (press proofs, OK sheets, first runs) and single page prints																														
Black (K)	16	0	0	32	1	0	16	0	0	31	1	1	19	1	2	19	1	2	23	1	2	22	1	2	31	1	3			
Cyan (C)	55	-34	-52	58	-22	-47	54	-36	-49	58	-25	-43	56	-36	-45	54	-35	-41	54	-32	-41	54	-35	-38	56	-28	-36			
Magenta (M)	47	74	-5	54	58	-4	46	72	-5	54	58	-2	46	70	-7	45	68	-5	48	64	-3	47	63	-3	50	56	-3			
Yellow (Y)	87	-4	90	86	-3	70	87	-6	90	86	-4	75	84	-4	86	82	-3	85	81	-2	77	80	-2	83	79	-1	69			
Red (M +Y)	47	68	45	52	55	25	46	67	47	52	53	25	46	62	42	45	61	42	47	60	37	46	59	39	48	54	29			
Green (C+Y)	49	-65	24	51	-41	11	49	-63	26	53	-42	13	49	-57	26	49	-54	28	49	-51	23	48	-52	25	50	-42	16			
Blue (C+M)	25	21	-47	38	10	-31	24	21	-45	37	8	-30	27	16	-45	27	15	-41	28	17	-38	27	12	-39	36	8	-31			
C + M + Y	23	-1	-2	34	1	-4	22	0	0	32	0	0	27	-4	-1	27	-2	-1	27	2	-3	26	-2	-3	33	-3	5			
Paper tone	93	1	-7	92	2	-10	93	0	-3	92	0	-3	89	0	-1	87	0	0	87	0	-2	86	-2	3	86	-1	2			

MediaStandard Print 2016, CIEL*a*b* color values of the solid base colors for sheetfed, web and continuous offset

Tolerances for solid coloring on white and black backing						
Criterion	**Press proof** (differences over the format ≤ 8 % of the lowest measured solid density for the primary color in question)		**Production print differences**		**Production print fluctuations**	
	normative	**informative**	**normative**	**informative**	**normative**	**informative**
Black (K)	$\Delta E^*_{ab} = 5$	$\Delta E^*_{00} = 5$	$\Delta E^*_{ab} = 5$	$\Delta E^*_{00} = 5$	$\Delta E^*_{ab} = 4$	$\Delta E^*_{00} = 4$
Cyan (C)	$\Delta E^*_{ab} = 5$	$\Delta E^*_{00} = 3.5$	$\Delta E^*_{ab} = 5$	$\Delta E^*_{00} = 3.5$	$\Delta E^*_{ab} = 4$; $\Delta H^*_{ab} = 3$	$\Delta E^*_{00} = 2.8$
Magenta (M)	$\Delta E^*_{ab} = 5$	$\Delta E^*_{00} = 3.5$	$\Delta E^*_{ab} = 5$	$\Delta E^*_{00} = 3.5$	$\Delta E^*_{ab} = 4$; $\Delta H^*_{ab} = 3$	$\Delta E^*_{00} = 2.8$
Yellow (Y)	$\Delta E^*_{ab} = 5$	$\Delta E^*_{00} = 3.5$	$\Delta E^*_{ab} = 5$	$\Delta E^*_{00} = 3.5$	$\Delta E^*_{ab} = 5$; $\Delta H^*_{ab} = 3$	$\Delta E^*_{00} = 3.5$

Checking proofs for color fidelity

		Tolerances acc. to ISO 12647-7 (it is not possible to convert between new and old)			
Test criterion	**Measurement patches in the Fogra media wedge**	**new (-7:2016)** based on the CIEDE2000 color difference formula		**old (-7:2007)** based on the CIELAB (1976) color difference formula	
Paper white	C 21	Measured value	$\Delta E^*_{00} \leq 3.0$	Measured value	$\Delta E^*_{ab} \leq 3$
Overall inking	all	Mean value	$\Delta E^*_{00} \leq 2.5$	Mean value	$\Delta E^*_{ab} \leq 3$
		Maximum value	$\Delta E^*_{00} \leq 5.0$	Maximum value	$\Delta E^*_{ab} \leq 6$
Primary color solids	A1, A6, A11, A21	Maximum value	$\Delta E^*_{00} \leq 3.0$	Maximum value	$\Delta E^*_{ab} \leq 5$
		Maximum value	$\Delta H^*_{ab} \leq 2.5$	Maximum value	$\Delta H^*_{ab} \leq 2.5$
Chromatic gray	B16 to B21	Mean value	$\Delta C_h \leq 2.0$	Mean value	$\Delta H^*_{ab} \leq 1.5$
		Maximum value	$\Delta C_h \leq 3.5$	–	
Solids, poss. spot color halftones	–	Maximum value	$\Delta E^*_{00} \leq 2.5$	–	

ΔE* = Color difference, ΔH* = Hue difference, ΔCh = Chroma difference

5.5. The advantages of colorimetry in offset printing

In summary, here is an overview of the main advantages of colorimetry in offset printing:

- The measurement values match the visual perception of the colors very closely.
- Colorimetry is a process-independent color evaluation method that can be used throughout the printing process from prepress to all kinds of proofs to the final quality control of finished products.
- Colorimetric reference values can be expressed in figures. They can also be integrated into prepress.
- Colorimetric reference values can be taken from samples.
- Colorimetry is the only way to ensure objective evaluation.
- Colorimetry enables image-relevant color control (for instance using gray patches) without calibration of individual colors or stored conversion tables.
- Colorimetry can be used to control all colors, including very light spot colors, correctly and reliably.
- Dot gain in spot colors can also be precisely measured with spectral measurement.
- Control of the production print run is more reliable, because changes in the substrate, ink soiling and metamerism can be measured and taken into account.
- Halftone printing with more than four colors can also be controlled correctly.
- Print quality can be described and documented more effectively. There is a measure of color deviation that is independent of color hue – ΔE.
- Colorimetry enables the printing industry to liaise with all other industries in which color plays an important role.
- Densitometry, for example to determine dot gain, is an integral part of spectral color measurement.
- Image areas can also be compared with originals.

5.6 Using colorimetry for color control

Unlike density control systems, colorimetric color control always aims at approximating the desired color as closely as possible. This is done as follows: The $L^*a^*b^*$ value **1** saved in the color archive of the color measuring system is the basis of measurement and control. This value is always based on the paper white on which the ink was printed at the time it was stored/archived. The system now calculates the target color coordinates **2** that would be achieved with the identical ink, but using the current paper. This color is now the reference value that is used for all evaluations.

After the first color measurement, the system knows the spectrum of the current ink and calculates the **color line.** This line represents the changes of the target color's coordinates if the film layer thickness is increased or decreased. At the same time, the system determines the color coordinates 3 that come closest to the color coordinates 2 on the color line. The difference between the calculated target color coordinates **2** and the actually achievable color coordinates **3** is termed ΔE_0 or best match and displayed to the press operator.

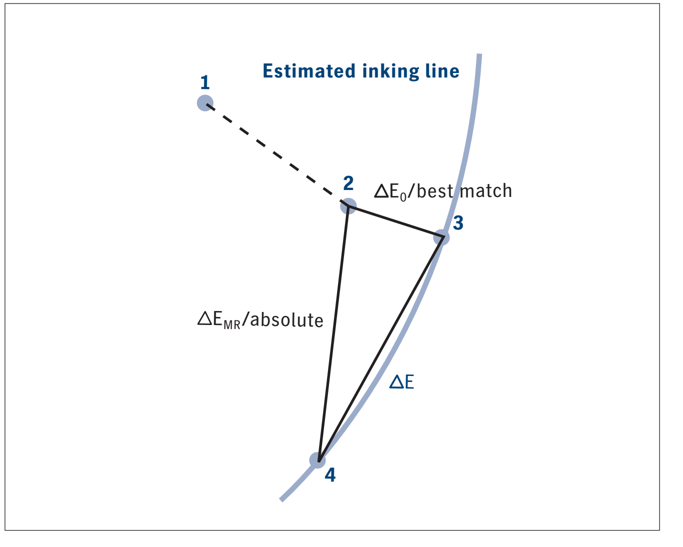
Position **4** shows how far away the measured color is from the best achievable color coordinates **3,** i. e. the best possible color match; this value is displayed as ΔE. The press operator can eliminate this difference by increasing or decreasing the ink quantity.

Quality Assist, when used in conjunction with Prinect Inpress Control and the Wallscreen XL, permits automatic press makeready according to ISO 12647-2 as well as production control in compliance with the relevant standards. To this end, the system simultaneously analyzes the absolute color difference ΔE_{MR} between the target color coordinates **2** and the current color **4** and the adjustable ΔE between **3** and **4.**

The MR in ΔE_{MR} stands for makeready. Another term that is frequently used is absolute color deviation. As soon as ΔE_{MR} corresponds to the OK sheet tolerance of the ISO standard and ΔE is within the production tolerances, the system signals to the press operator that production may begin. The system can be set to automatically switch from makeready to production and start the good sheet counter.

In cases where an adjustment to the paper white is not desired or makes no sense, the target coordinates **2** are eliminated, i. e. they are identical with **1.** This usually results in a larger best match/ΔE_0 value. This is the case in the following scenarios:

1. Manual input of $L^*a^*b^*$ values
2. Manual changes to measured $L^*a^*b^*$ values
3. Selection of Pantone and HKS inks (depending on the software version of the press)
4. Selection of the target color according to ISO 12647-2/FOGRA51-52



Example of a color line in the CIELab color space.

Glossary

Color management
A method/system for coordinating the individual devices and presses involved in the workflow from color image processing through to the finished print result. Color management is used to ensure correct color reproduction from input to output, for example on printing presses. For some time now, it has also been used to ensure color fidelity in various printing systems such as inkjet proof, offset and digital printing.

Densitometer
A device that measures density. Reflection densitometers are used in printing. To determine the density, the paper white measurement is compared to the measurement results in the required color area.
> Density

Density
The degree to which an ink layer is impermeable to light. Mathematically this is the relationship between a measurement on unprinted paper and a measurement on printed paper.

Characteristic curve
The graphical representation of the relationship between the tonal values of prepress data, usually tonal values of halftone data, and the associated tonal values in print.
> Dot gain

Ink fading
Term for the decline in the thickness of the ink film in the circumferential direction in offset printing.

Color deviation ΔE
ΔE describes the color deviation between two colors and can be calculated as the distance of the $L^*a^*b^*$ values between the two colors.

Ink film thickness/ink level
The physical thickness of the ink applied. The ink film thickness essentially determines the density value of a color area.

Area coverage
The ratio of the area covered (with image elements) to the total area. Area coverage is generally specified as a percentage. A distinction is made in printing between the effective area coverage calculated from optical measurements and the geometric area coverage calculated from area measurements.

Actual value
The value actually measured in a sample.
> Reference value

Metameric colors
Metameric colors are colors with different spectra that look the same under one illuminant but different under another. We call this metamerism.

Measuring Conditions
Since 2009, ISO 13655 has permitted spectral measurement in the print under a number of different measuring conditions.

M0 = former CIE illuminant A with a slight, undefined UV portion.

M1 = corresponds to CIE illuminant D50 with a defined UV portion that excites the usual optical brighteners in printing paper. This means the illuminant must include a defined UV portion in addition to the visible light spectrum. Ideally, the spectral distribution should always be in the range of 380 nm to 730 nm.

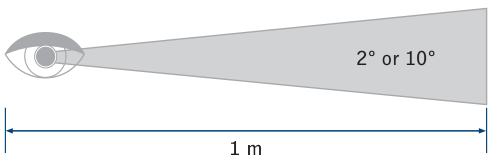
M2 = not clearly defined illuminant, which must nevertheless not contain any UV light. As the fluorescence of optical brighteners is excited mainly in the range between 340 nm and 420 nm, a continuous spectrum between 420 nm and 730 nm would be desirable. However, as we also want to be able to measure the reflectance in the range between 400 nm and 420 nm, the manufacturer must determine the ideal range for his device and the optimum measurement.

M3 = M2 + polarization filter

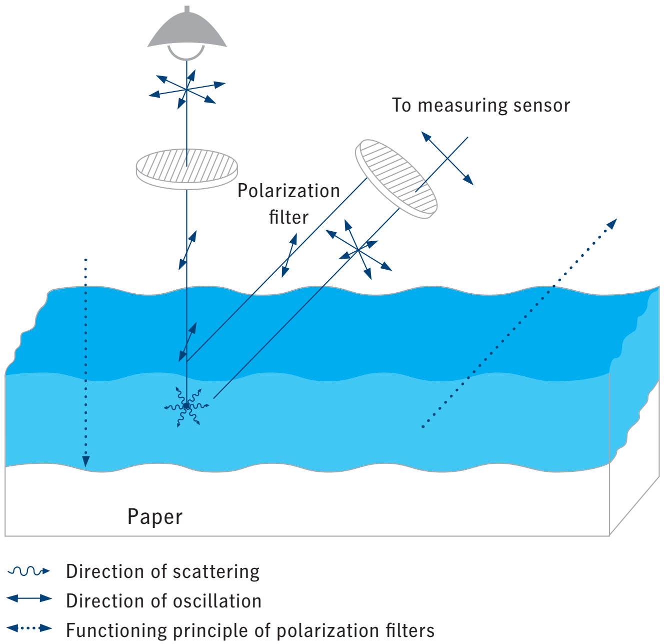
Mini Spots
Small print control elements that can be located anywhere on standard production jobs because they only take up a limited amount of space. The measurement values are then evaluated with the Quality Monitor, and any required process or profile adjustments are made using the Calibration Tool or Profile Tool in the Prinect Color Toolbox.

Nanometer (nm)
Unit of length, 1 nm = 0.000001 mm. For example: fine hair has a diameter of 0.020 mm; a thousandth of 0.020 mm is 0.000020 mm, i. e. 20 nm.

Standard observer
The chromatic response of the average standard observer to a specific color area was defined in a test series. The 2° angle test is based on the typical reading situation for books or magazines. The 10° experimental setup simulates looking at a billboard.



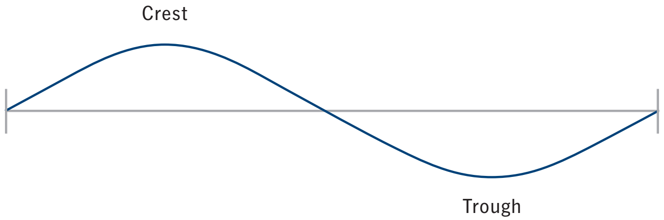
Polarization filter
A polarization filter can be inserted in front of a densitometer for a density measurement. Polarization filters are used to filter out the glare of the reflected light. This means it is irrelevant whether the print sample is wet or dry during measurement. One drawback is, however, that using a polarization filter increases the density measured in the print sample.



Reference value
Guideline value for a measurement sample. The aim of every control operation is to ensure the smallest possible difference between the reference or target value and the actual value. > Actual value

Dot gain
Optical and mechanical process conditions result in an increase in the size of halftone dots when they are printed on paper in comparison to their size in the original digital data. Dot gain measures the difference between the visually perceived area coverage and the area coverage in the data. > Area coverage

Wavelength
The physical length of a wave period.



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