H43: Reproduction of Images: Colour Printing

Four-colour printing is the method used for the reproduction of coloured illustrations in many newspapers, magazines and on packaging materials. The technique is based on the trichromatic nature of human colour vision in that, under normal viewing conditions, there are three signals arising from the cone shaped sensors in the retinal layer of the eye. If the three signals are the same when viewing the reproduction as those when viewing the original then the reproduction will appear to have the same colour as the original. Colour printing achieves this by controlling the amount of light reflected by the print by means of a combination of subtractive and additive colour mixing.

Subtractive colour mixing

Colour printing makes use of three specially formulated transparent printing inks known as process inks. In a set of ideal process inks, each of the inks would absorb (or ***subtract***) one particular band of wavelengths, roughly a 1/3 of the visible spectrum, from the light passing through the ink layer. Each band is associated with one of the colour signals of the eye and may be specified as including those wavelengths where the main appearance characteristic is the hue associated with that colour signal. The most common set of bands is shown in Table 1. The light with wavelengths associated with blue form the band 380 nm to 490 nm, green wavelengths form the band 490 nm to 580 nm and red wavelengths form the band 580 nm to 730 nm.

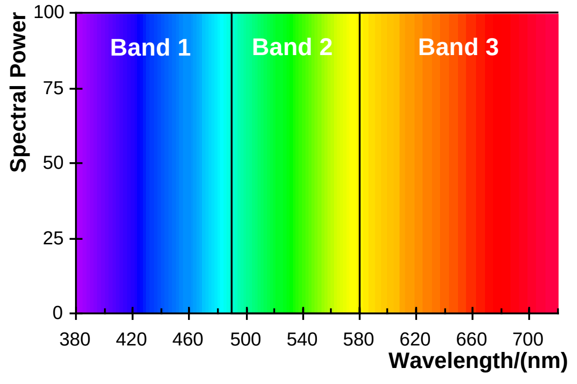


Figure 1: Each process-ink is designed to absorb light with wavelengths in one of the three bands

Table 1: Wavelength Bands of Ideal Process Inks

Appearance of Ink	Light Absorbed	Wavelengths absorbed	Light Transmitted
Yellow	Blue	380 nm to 490 nm	Green and Red
Magenta	Green	490 nm to 580 nm	Blue and Red
Cyan	Red	580 nm to 730 nm	Blue and Green

In a set of inks with ideal optical properties the absorptions bands do not overlap each other. The bands of the three inks cover the whole spectrum so that mixing the ideal inks together would form black ink. Note that any overlap in the absorption bands would reduce the ability of the set of inks to reproduce strong, bright colours.

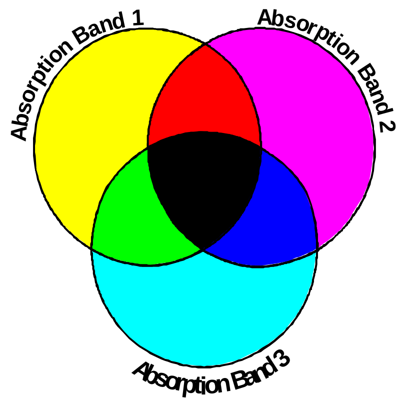


Figure 2: Overprint colours

The amount of each process ink in the printed layer controls the amounts of light reflected in the red, green and blue bands and hence the colour of the print. The yellow ink, for example, controls the amount of blue light reflected from the white substrate by absorbing (subtracting) the blue light from the white light. Figure 2 illustrates that a red, a green, a blue colour and a black can be produced as a result of printing one ink layer on top of another.

Generating tones

The lithographic and letterpress printing processes cannot print varying thickness of ink, but can print varying areas of ink at a constant thickness. The half-tone process achieves full tonal reproduction where the image is split into a mosaic of dots of different area. The half-tone principle was first used to create monochrome prints such as that shown in the Figure 3.

The image Figure 3 has been magnified many times to make the individual dots clearly visible. The area of the dot depends on the intensity of light reflected by the original at that point. Some detail is lost in the process but this is usually not noticed, for example a 150-line screen would have 150 x 150 dots or 22,500 dots in each square inch.

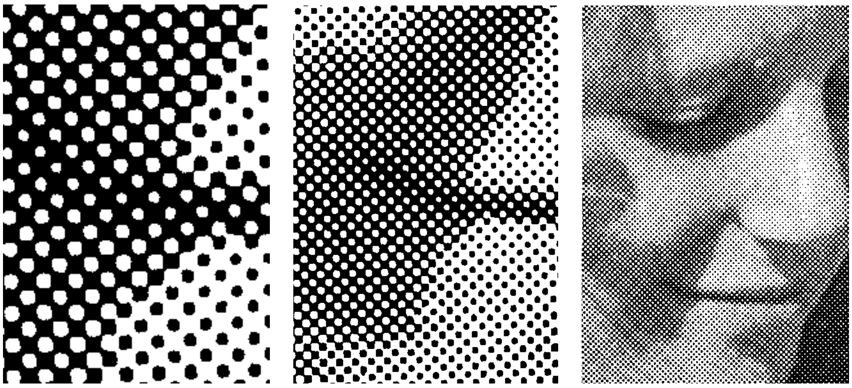


Figure 3: The eye blends the dots together to give the impression of grey tones

Resolution of the eye

The resolution of the unaided eye determines the dot spacing required for printing and scanning of graphic images to produce a satisfactory reproduction. The resolution can be defined as the least distance between two points that can be recognised as separate items. This occurs for the eye when the images of the two points fall on adjacent light receptors (cones) in the fovea of the retina. This will be the case when the difference between the angles subtended to the eye by the two points is about 1 minute of arc. For objects that are at the distance of most distinct vision (25 cm) the separation between the points will be about 0.07 mm (73 μm). Move the objects closer to the eye and the points cannot be distinguished because they are out of focus. Move the objects further away from the eye and they cannot be resolved because the images on the retina are closer together than the spacing of the cones.

A resolution of 73 μm is equivalent to 350 dpi (dots per inch). Note that flatbed scanners for personal computers are routinely available with 1200-dpi or 2400-dpi resolution. These devices have a resolution equivalent to 21 μm and 11 μm, three and six times better than the human eye respectively. They can provide both recording and useful magnification of an image.

Coloured image reproduction

To reproduce a wide gamut of colours it is necessary to be able to print varying amounts of the four inks. The lithographic, flexographic and letterpress printing processes cannot print varying thickness of ink, but can print varying areas of ink at a constant thickness.

The half-tone process achieves full colour reproduction by splitting the image into a mosaic of coloured dots of different area.

The dot area is so small that there will be several hundred even in the smallest part of the image that the eye can resolve, as shown in Figure 4.. The eye will see the colour from the sum of the light reflected by the

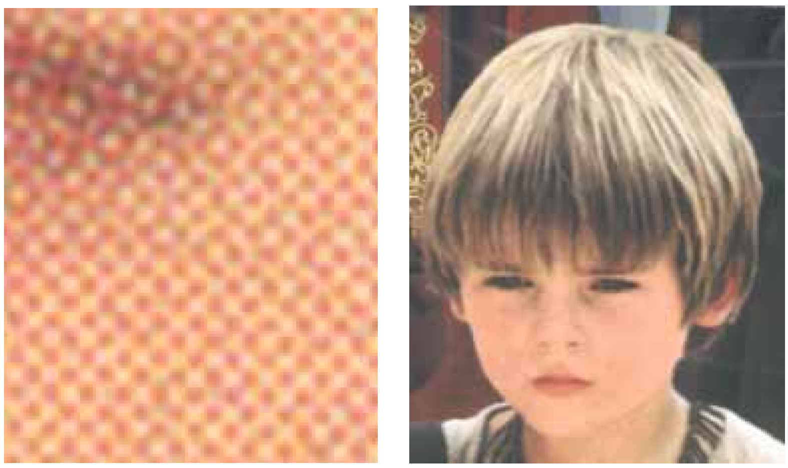


Figure 4: The dot pattern in a half tone coloured image

mosaic of dots in each part of the image. The variation in dot area and dot colour creates the impression of a full tonal coloured image.

There is a set of dots for each of the process inks so the printing process requires several printing plates, one per ink. Each dot position can either have a single layer of ink, two layers of ink or three layers of ink to produce a dot of one of the eight colours (white, cyan, yellow magenta, red, green, blue and black), as shown in Table 2.

Table 2: Dot colours in the half tone process

Dot Type	Layers	Dot Colour
1	None	White
2		Cyan
3		Yellow
4		Magenta
5	Yellow + Magenta	Red
6	Yellow + Cyan	Green
7	Cyan + Magenta	Blue
8		Black

Partitative colour mixing

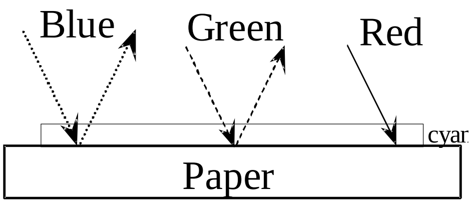
The colour of the dot is formed by subtractive colour mixing and the colour of the mosaic is perceived through additive colour mixing. The combined process, additive and subtractive has its own name, partitative colour mixing.

Colours of process inks

The spectral properties of process ink can be illustrated by the transmittance spectrum of the ink layer. The transmittance at each wavelength is the ratio of the reflectance of a print made with the ink to the reflectance of the white substrate. Each diagram displays the transmittance of ideal ink and that of typical process ink and shows that the spectra of the process inks only approximately match those of the ideal inks. ***transmittance*** = 100 × (reflectance of print)/(reflectance of substrate)

Cyan

The cyan ink absorbs the red light and transmits the green and blue. The ideal transmission spectrum is shown in Figure 5 along with the spectrum of typical process ink.



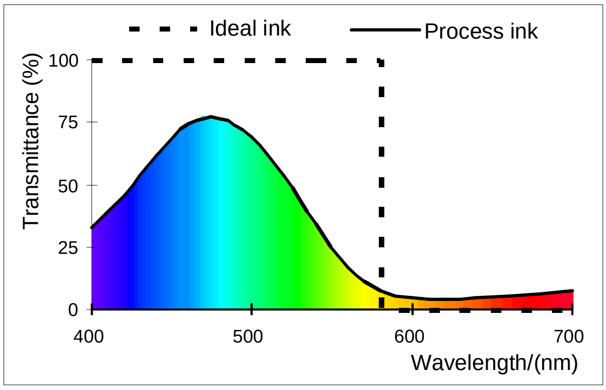
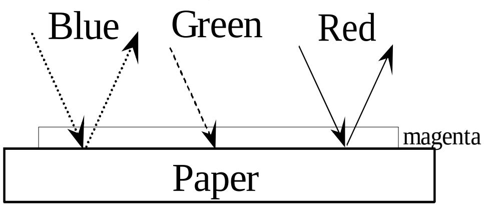


Figure 5: Transmittance of cyan ink

Magenta

The magenta ink absorbs the green light and transmits the red and blue. The transmittance spectrums of ideal and typical magenta process ink are shown in Figure 6.



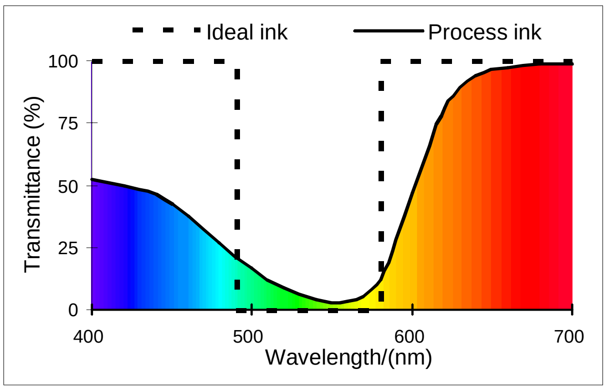
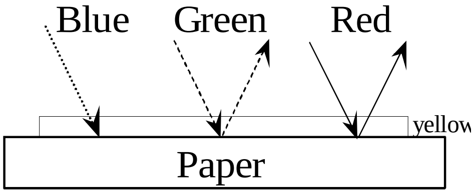


Figure 6: transmittance of magenta ink

Yellow

The yellow ink absorbs the blue light and transmits the red and green. The transmittance spectrums of ideal and typical yellow process ink are shown in Figure 7.



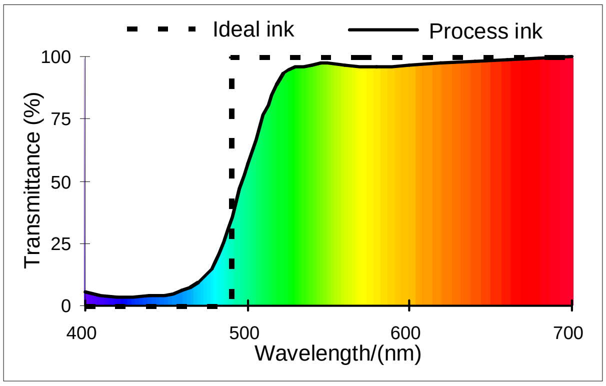
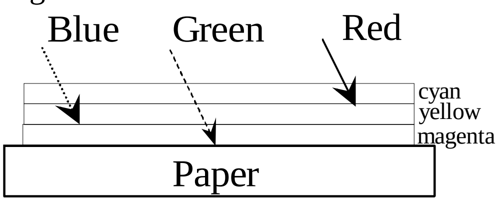


Figure 7: Transmittance of yellow ink

Black

The strengths of the process inks are chosen so that a layer containing equal amounts of cyan, yellow and magenta ink would have a neutral grey or black appearance. In practice, a black produced in this way can be brownish in hue and not particularly strong, therefore the fourth process ink, black, is required. In addition, it is more economical to use black ink rather than overprinting with three, expensive, coloured inks.

The transmittance spectrums of ideal black, a typical process black and an overprint of cyan, yellow and magenta are shown in Figure 8



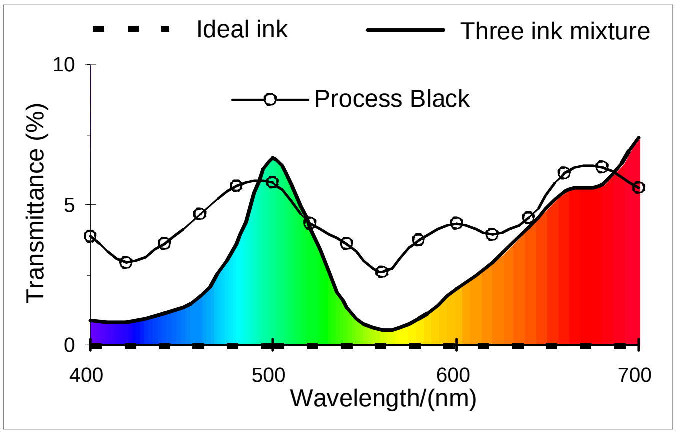


Figure 8: Transmittance of black ink

Colour separation and reproduction

A set of dots is printed for each of the process inks so the printing process requires four printing plates, one per ink. Each position on the print can either have a single layer of ink, two layers of ink or three layers of ink to produce one of the eight colours shown in Table 1.

In the conventional method of printing plate production, the original is illuminated by strong white light and a lens and half-tone screen produces an image in the form of tiny dots. The half-tone image is recorded photographically and the plate prepared from the film through several additional stages of processing. Modern methods have replaced the photographic process by electronic image capture and computer based image analysis.

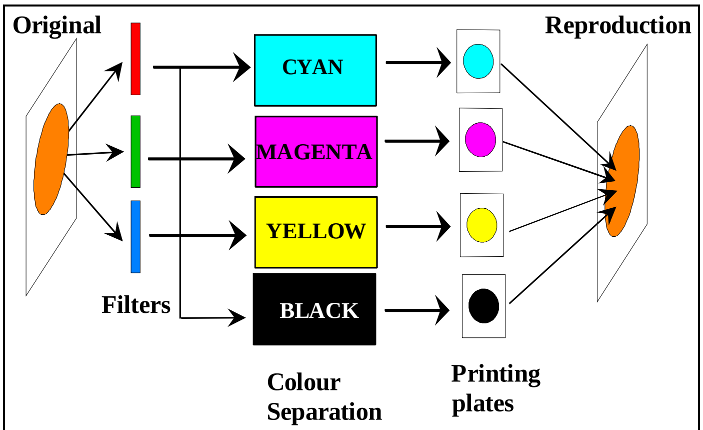


Figure 3: Representation of the separation and reproduction steps of printing

The process of colour analysis, separation and reproduction is represented schematically in Figure 3.

Colour separation is the first step in the production of the printing plates, the original is illuminated by strong white light and the reflected light is analysed by passing through a coloured filter. Three filters (red, green and blue) are needed for a full analysis; the transmission characteristics of each filter can be thought of as being an approximate representation of the cone response curves of the eye. Figure 4 shows the transmission characteristics of the Kodak Wratten set of colour separation filters.

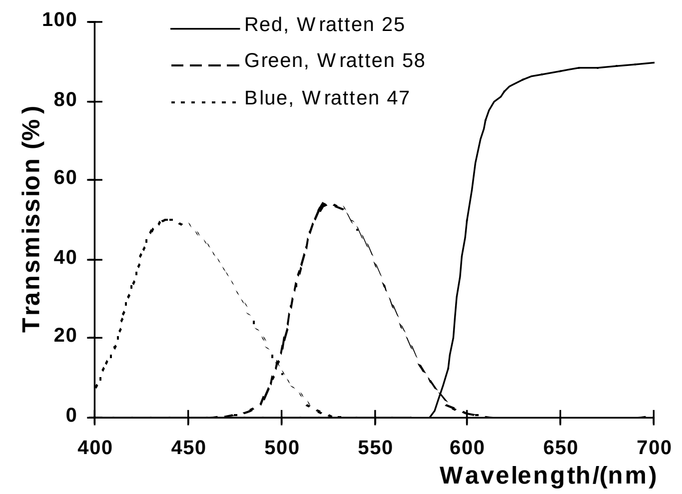


Figure 4: Transmission spectra of filters used for colour separation analysis.

The printing plate for the cyan ink is prepared from the image transmitted through the red filter, as illustrated in Figure 5. This is explained by noting that the cyan ink mainly absorbs the red light. Therefore, the amount of cyan ink on the print will determine the amount of red light reflected by the reproduction. The intensity of the image transmitted by the filter at each point is used to determine the area of ink to be printed at that point. The more intense the red filtered light, the smaller the area of cyan ink to be printed.

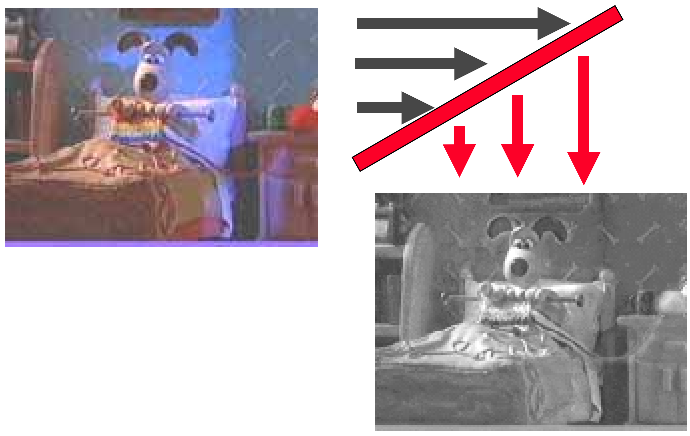


Figure 5: Red filter used to create the cyan ink plate

The plate for the magenta ink is prepared using the image transmitted through the green filter and the plate for the yellow ink is prepared using the blue filter. The printing plate for the black ink is prepared using a more or less neutral coloured filter.

Quality of reproduction

Colour fidelity

Subtractive colour mixing, even with an ideal set of process inks cannot reproduce all of the colours that the eye can see. The total set of colours that a device can reproduce is called the ***gamut***. The gamut is represented on the CIE x, y chart shown in **Figure 9**. The outer, horseshoe shaped area "A" includes all the visible hues at intensities from neutral to fully saturated. The small central area "C" in the figure illustrates the gamut of four-colour printing, which can only reproduce about half of the colours that the eye can perceive.

The non-ideal nature of the practical set of process inks, in particular the overlapping of the light absorption bands means that green and blue shades tend to be reproduced darker than the original.

Spatial resolution

The resolution of the unaided eye determines the dot spacing required for printing and scanning of graphic images to produce a satisfactory reproduction. The resolution can be defined as the least distance between two points that can be recognised as separate items. This occurs for the eye when the images of the two points fall on adjacent light receptors (cones) in the fovea of the retina. For objects that are at the distance of most distinct vision (25 cm) the separation between the points will be about 0.07 mm (73 µm). Move the objects closer to the eye and the points cannot be distinguished because they are out of focus. Move the objects further away from the eye and they cannot be resolved because the images on the retina are closer together than the spacing of the cones.

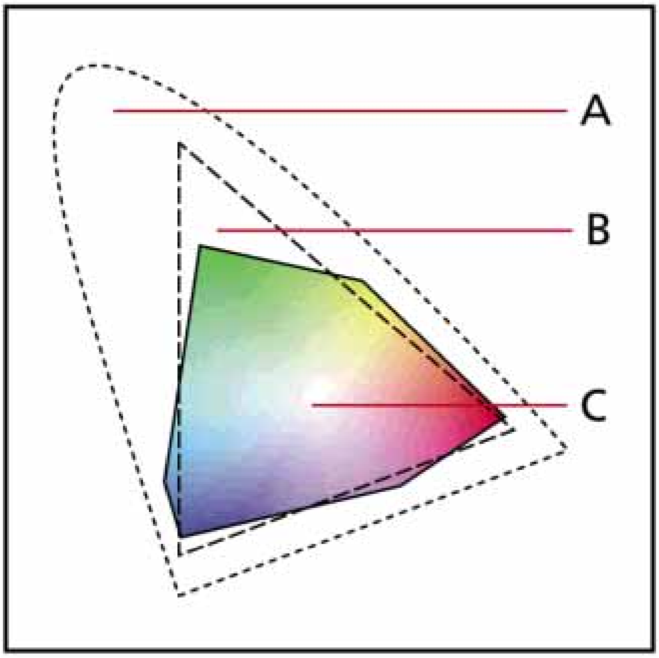


Figure 9: x y chart of colour gamut. (A) all colours, (B) RGB display, (C) CYMK print

A resolution of 73 µm is equivalent to 350 dpi (dots per inch). Note that low-cost flatbed scanners for personal computers are routinely available with 1200-dpi resolution. These devices have a resolution equivalent to 21 µm, three times better than the human eye.

Most problems associated with accurately reproducing colours by four colour printing stem from reconciling the limitations of the gamut produced by the cyan, magenta, yellow, and black inks of a printer. Although the non-ideal properties of the process inks can cause significant systematic errors in the reproduced colours, the overall effect is usually accepted as a good reproduction.