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# WHAT'S IN A COLOUR?

Useful insights into pigment mixing and colour values for paint labs. By Werner Rudolf Cramer.

**Testing shows that coloured pigments display the same optical behaviour in mixtures with achromatic pigments. This applies to white pigments as well as to aluminium and white interference pigments. However, the way that coloured pigments react in a mixing series differs for green and blue-coloured pigments compared with yellow and red-coloured pigments.**

The range of coloured pigments includes both inorganic and organic pigments. Both groups can be further divided based on their chemical structure. For these experiments into the optical properties of coloured pigments, we mixed tints in several mixing steps with a white tint as well as with an aluminium and a white interference tint from the respective mixing systems. With these achromatic coatings, the optical reactions of the selected coloured pigments show the same optical behaviour in these mixtures: Green and blue-coloured pigments react in the mixing series with a turning point, which is missing in yellow and red-coloured pigments.

## OBJECTIVE COLOUR MEASUREMENT

All mixing panels were measured colourimetrically, with the chosen measuring geometry 45°/as45° (illumination/observation) for assessment. The near-gloss geometry 45°/as15° was chosen for the blends with an aluminium or white interference pigment. A main focus of the evaluations was also the comparison of the reflectance curves with the colour values L*a*b*: On the one hand, the reflectance curves reflect the physical-optical properties of a pigment, on the other hand, the colour values calculated from the reflectance values defined the physiological properties. This "translation" of the physical values into physiological colour values represents a decisive step for colour assessment. The L*a*b* colour values show the employee or nuancer in the paint laboratory the unambiguous colour position of their painted panel. Colour measurement makes it possible to achieve objective representations, independent of subjective assessments.

Although the colour values also reflect the usual representation of a colour, they are more easily recognisable after conversion into L*C*h° values. While the a*b* values represent the proportions on the corresponding red-green and yellow-blue axes in the coordinate system and thus determine the chromaticity coordinate, the L*C*h° representation provides better clarity: the L* value is the same for both types of representation, the C* value is calculated from the a*b* values and shows the distance of the chromaticity coordinate from the zero point of the coordinate system. The C* value stands for the chromaticity of the pattern. The h° value is given in degrees and results in the angle to the red axis (+a*). This describes a colour: Hue (h°), chroma (C*) and lightness (L*). This classification also corresponds to our colour perception.

## REFLECTION CURVES CLARIFY OPTICAL PROPERTIES

Our current colour theory is based on assumptions from the 19th century. Alexander von Humboldt developed the three-colour theory (three-zone theory), according to which our vision is based on the

## RESULTS AT A GLANCE

→ Coloured pigments can be divided into two categories based on their optical properties: Green and blue-coloured pigments have a reflection maximum, yellow and red-coloured pigments have a reflection plateau.

→ This distinction also affects their behaviour towards mixtures with achromatic pigments.

→ Green and blue-coloured pigments show a turning point when mixed with an achromatic pigment. Up to this turning point, the chromaticity of the mixtures increases, after which it drops towards achromatic pigment.

→ With yellow and red-coloured pigments, no inflection point is found in mixing series. Here, the mixing series run more or less directly between the coloured pigment and the achromatic pigment.

three primary colours of red, green and blue. The four-colour theory of Ewald Hering, who developed the theory of opposite colours, provides a contrast to this. Here, the colours yellow and blue and red and green were opposite each other. This corresponds to our sensations, according to which no yellow is bluish and no blue is yellowish. The same applies to red and green: no red can be greenish and no green can be reddish. Both theories were combined by Kries to form the zone theory, which also became the basis for the CIE representations. Professor Wilhelm Ostwald, Nobel Prize winner for the definition of catalysis, and Henry William Munsell also contributed significantly to the physiological view of colours.
However, this information is not sufficient for nuancing, because the perception of colour happens in our heads and is only influenced to a limited extent by the pigments. The eye and the brain do not care whether an orange has been mixed from yellow and red or whether it is present as a single pigment. Since the brain "translates" the reflections into colour sensations, it does not recognise certain pigment properties: A yellow pigment reflects not only in the yellow spectral range, but also in the green and the red. Both ranges are mixed to yellow by the brain and result in a bright and intense colour within the yellow range.
Mixed orange also has a saddle shape in its reflection compared to an orange pigment and is easily recognised as such. Purple, which the brain composes from the two colours at the respective end of the spectrum and does not occur in the spectrum, can also be determined by its reflection curves. Reflection curves are important in the assess-

Figure 1: Coloured pigments can typically be divided into those with a reflection maximum (green, blue) and those with a reflection plateau (yellow, orange, red).

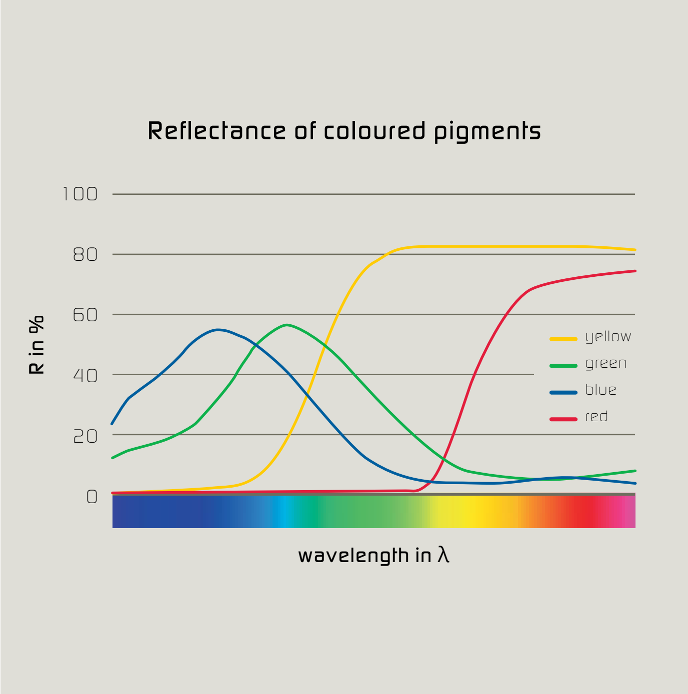
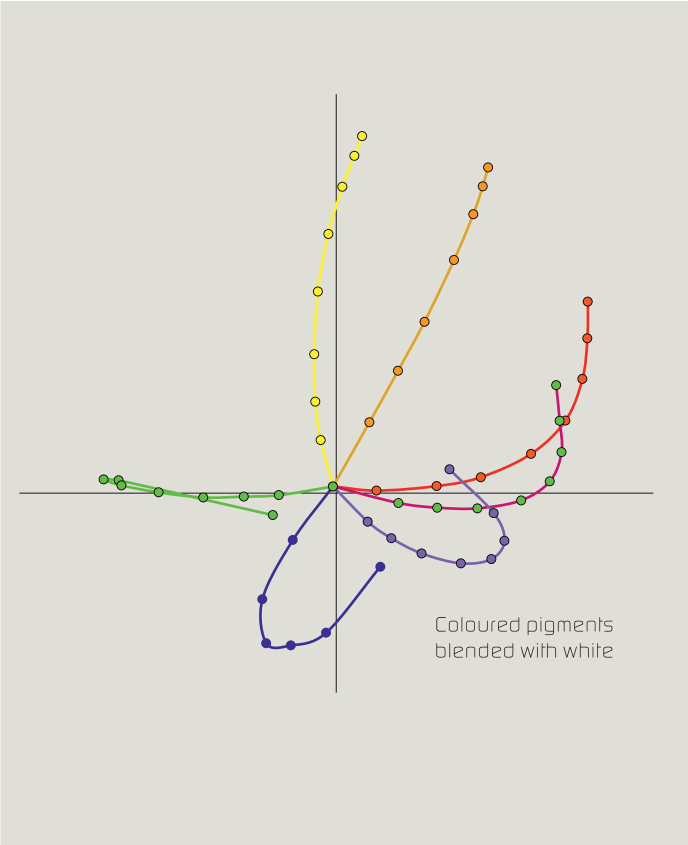



Figure 2: Mixing series of yellow and red coloured pigments with white run more or less between the starting pigments. Corresponding mixed series with blue or green chromatic pigments show a turning point with maximum chromaticity. Shown are the red-green colour values on the x-axis and the yellow-blue colour values on the y-axis.



ment of coloured pigments as well as aluminium and interference pigments. In the case of interference pigments, the resulting colour depends on the angle of illumination and the angle of observation.
For these reasons, we need an evaluation based on the reflection curves and the calculated colour values. This is the only way to understand the optical properties of a coloured pigment and its mixtures with achromatic pigments.

## COLOURED PIGMENTS ARE NOT COLOUR NEUTRAL

All the examined coloured pigments show that they do not provide ideal colours. Depending on the chemical basis and manufacturing process, they vary in colour – there are no neutral colours among pigments. Due to their colour character, they tend in different directions. A yellow pigment can be reddish or greenish, but never bluish. If I work in the reddish range, it makes no sense to tone with a greenish yellow. You should always tone with the pigments that are closest in colour. Pigments also have a different colour strength, i.e. you should start with the yellow pigment and add a little red to make an orange mixture. If you were to start with a red, you might end up needing a hundred times the amount of yellow to create orange.
Besides the description about their hue, chroma and brightness, coloured pigments can be divided into two groups based on their optical behaviour. One group includes the pigments whose reflections show a pronounced maximum. This applies to blue, green and blue-violet pigments. They show maxima in the shorter wavelength spectral range

Figure 3: Simulated spray-out panels show the turning point and A and B sides for the blue-white mixing series.

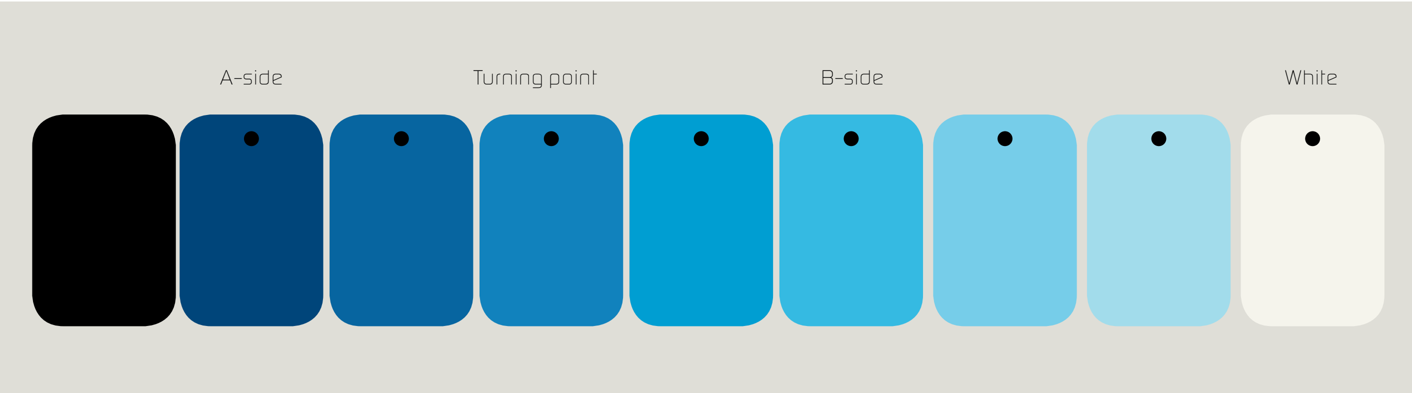



Figure 4: A mixing series of an aluminium pigment with a green or blue chromatic pigment shows the same optical behaviour as for white: the chromaticity increases up to the turning point and then decreases in the direction of the aluminium pigment.

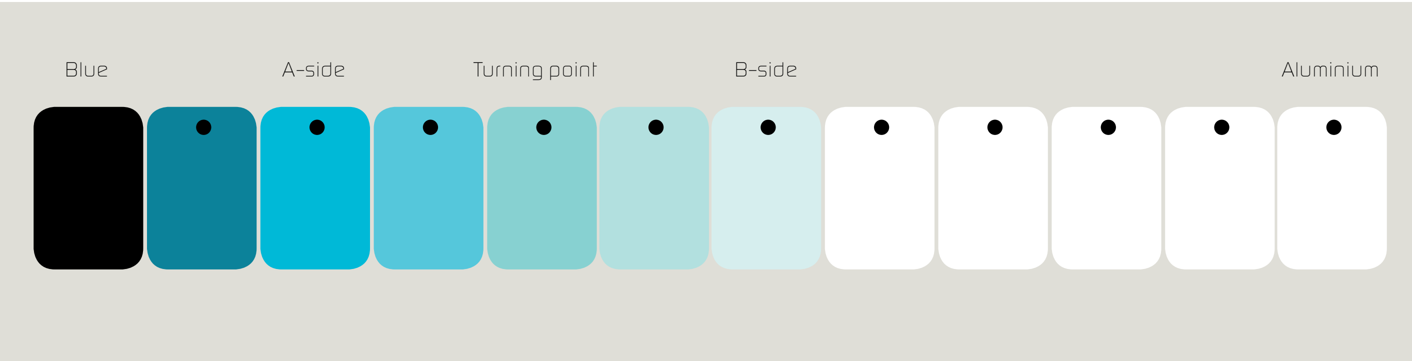
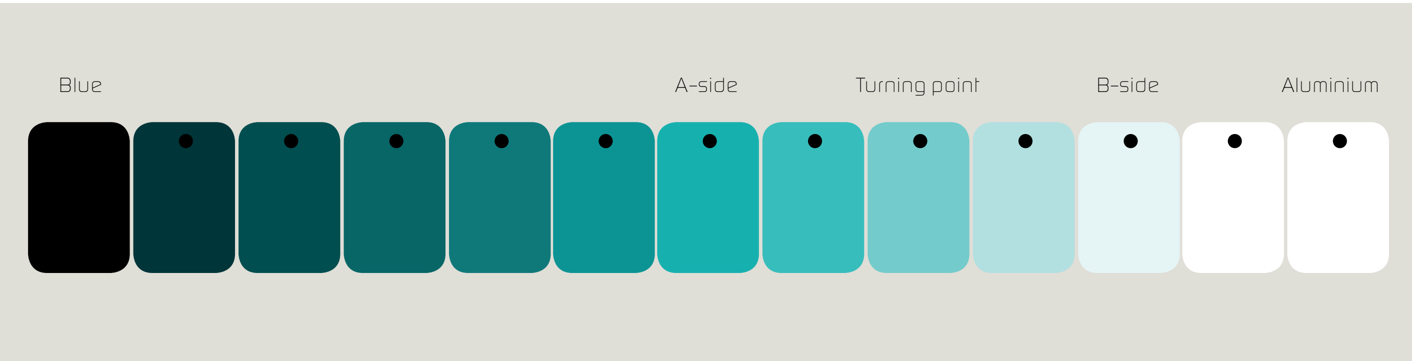



Figure 5: Comparable results are obtained when a white interference pigment is mixed with a blue or green chromatic pigment. There are two sides to the turning point where chroma increases or decreases when white interference pigment is added.



with corresponding flanks. In contrast, the second group includes yellow, orange and red pigments and has striking reflection plateaus. Here, the reflection increases towards the longer wavelength spectral range and remains at a high reflection level until the end of the spectrum. The position of the flank to this reflection plateau is typical for yellow, orange or red (*Figure 1*).

The differentiation of the coloured pigments according to their optical properties was the basis for further experiments with mixed series involving achromatic pigments. For this purpose, we selected a white pigment as well as aluminium and white interference pigments. The results were basically the same and will be presented with selected examples.

## COLOURED PIGMENTS WITH WHITE

The different reflection behaviour of the coloured pigments is also reflected in the different mixing behaviour with white pigments. If yellow and red-coloured pigments are mixed with a white pigment, the mixing row runs more or less directly between the pigments. A yellow-coloured pigment can make a slight “swerve” towards olive green when mixed with a white pigment, but otherwise finds its direct way to the achromatic white. Red pigments often show a greater swerve towards bluish when mixed with white. But even then, the series of resulting mixed colours goes between the two original colours (*Figure 2*).

Blue and green pigments show a different mixing behaviour: If they are mixed with white, the chroma and brightness initially increase. When they reach the turning point, the chroma starts to decrease, while the brightness continues to increase towards white. The connecting curve of the colour values resembles a loop with an inflection point at the highest chromaticity. While the chromaticity continuously decreases and the brightness continuously increases when yellow and red are mixed with white, the chromaticity of green and blue pigments changes when white is added. First, it increases and then decreases again from the inflection point.

This behaviour has an effect on shading. At a point between the blue pigment and the inflection point (A side), adding the blue pigment achieves a decrease in chroma and brightness. *Figure 3* shows simulated spray-out panels of a blue-white mixing series, indicating the turn-



Figure 6: A mixing series of the white interference pigment with the blue-green chromatic pigment showing chromaticity increasing up to the turning point and then decreasing toward the white interference pigment. The x-axis gives the panel numbers.

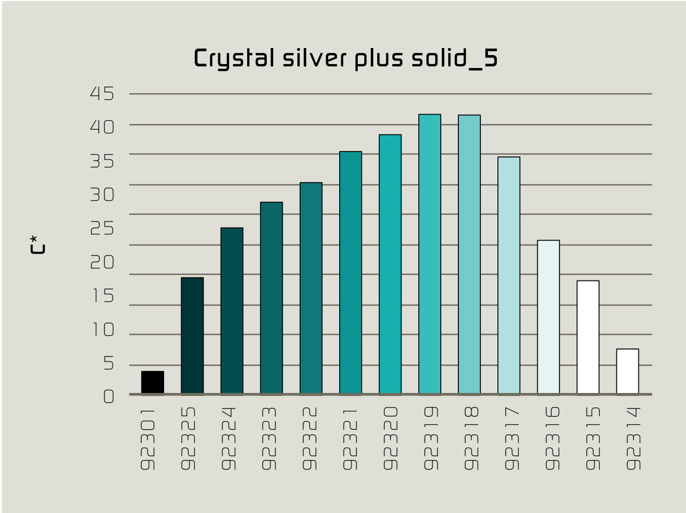



Figure 7: Brightness increases continuously as the amount of white interference pigment increases with no visible turning point. The x-axis gives the panel numbers.

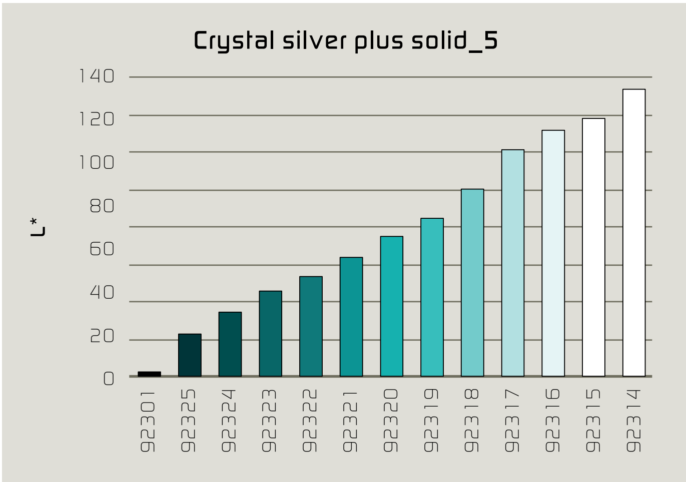
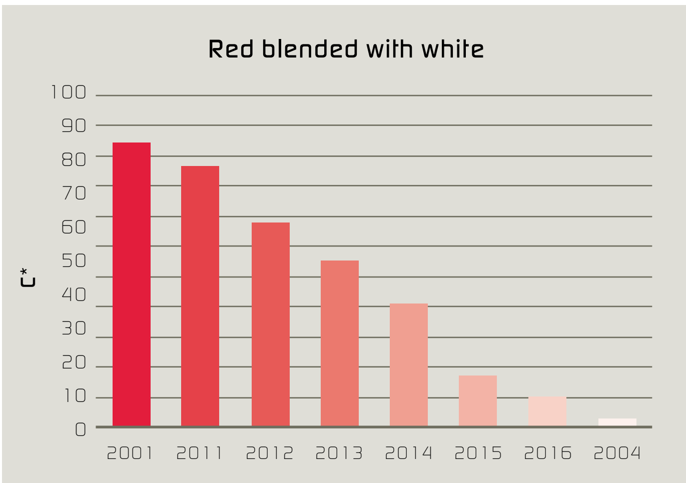



Figure 8: A comparison with a mixed series of a red-coloured pigment with white shows the continuous change of chroma without any inflection point.



ing point. The colours of the simulated spray-out panels are based on RGB values calculated from the measured reflectance values.
On the B-side between the turning point and the white pigment, adding the blue pigment would increase the chroma and decrease the brightness. Adding white instead of the blue pigment to a mixture between the blue pigment and the turning point (A-side), increases the chromaticity and brightness. On the B-side of the turning point, the addition of white would cause a decrease in chromaticity and an increase in brightness. For this reason, knowing the respective inflection point is important when nuancing.
The representation of the a*b* colour values in this mixing series does not show why blue and green chromatic pigments behave in this way. In the reflectance curves, only the short-wave range initially rises when white is mixed in. The turning point starts with the increase of the long-wave reflection range.

## COLOURED PIGMENTS WITH ALUMINIUM PIGMENTS

Aluminium pigments are divided into "cornflakes" and "silver dollars" according to their manufacturing process and differ in pigment size (flake size). Mixing tests with different aluminium pigments (mixed paints) show no differences in their behaviour compared to coloured pigments.
If an aluminium pigment is mixed with a blue or green pigment, the mixing series shows comparable behaviour to a mixing series with a white absorption pigment. Starting with the blue pigment, the chroma and the brightness of the mixture begin to increase when the aluminium pigment is added (*Figure 4*). As with a white pigment, the chroma and brightness increase until a turning point is reached. From this point (B side), the chroma decreases while the brightness increases in the direction of the aluminium pigment. Here, too, the addition of aluminium pigment increases the chroma and brightness when the colour is between the colour location of the blue pigment and the turning point (A side). If one is on the other side of the inflection point (B-side), the addition of aluminium pigment leads to a decrease in chroma with a simultaneous increase in brightness.
If blue pigment is added to a mixture whose colour location is between the blue pigment and the inflection point (A side), the chroma and brightness decrease. If the colour location on the B-side is between the turning point and the aluminium pigment, the addition of blue pigment causes an increase in chroma and a decrease in brightness. The aluminium pigment behaves the same as a white pigment when mixed with blue or green chromatic pigments. There is no discernible difference between the different types and kinds of aluminium pigments.

## COLOURED PIGMENTS WITH INTERFERENCE PIGMENTS

The same behaviour can also be observed with white interference pigments. White interference pigments show no colour shift in the visible spectral range compared to their coloured variants. A shift of the reflections due to the changed angle of the incident light occurs in the non-visible UV range. Despite or with the shift, however, coloured interference pigments also show the presented behaviour (*Figure 5*).
White interference pigments were first used in the colour range of car manufacturers in a 3-layer paint structure with white undercoat, effect basecoat and clearcoat. This was followed by various mixtures of pearlescent pigments with coloured pigments in almost all car manufacturers' colour programmes. Today, you can usually find combinations of all three types of pigments, exploiting their various advantages.
If white interference pigments are mixed with blue and green-coloured pigments, the same behaviour occurs as with the mixed series with white: first, chroma and brightness increase from the blue and green pigment up to a turning point (A side), from which the chroma decreases and the brightness continues to increase up to the white interference pigment (B side). Again, when shading, the side of the inflection point you start shading is important. Between the colour pigment and the turning point, chroma and brightness rise when adding the white interference pigment (*Figure 6*, *7*). On the B side of the inflection point, the chroma decreases and the brightness increases with adding further white interference pigment. Accordingly, chroma and brightness decrease when adding the coloured pigment to the mixture if you are on the A-side between the coloured pigment and the inflection point. On the B side of the inflection point, the chroma and brightness decrease when adding the coloured pigment (*Figure 8*).
Adding a white pigment, a white interference pigment or an aluminium pigment to a red or yellow-coloured pigment increases its low-reflectance spectral components faster and more than the high-reflectance spectral components. Thus, the reflections of a yellow pigment in the low reflection range can be about 90 times lower than those of a white pigment. In the longer wavelength range, the difference is much smaller. When white is added, the low-reflection range is disproportionately raised in reflection.
By using a green or blue coloured pigment, you initially increase their reflection maxima. If the low-reflection areas are then also raised, the resulting mixtures become less colourful and the chromaticity decreases. And the following mixtures continue to increase in brightness.

## REFLECTION CURVES PROVIDE INSIGHTS INTO MIXING

The reflection curves of the coloured pigments indicate two types: Blue and green-coloured pigments each have a reflection maximum, yellow and red-coloured pigments show a reflection plateau. With a white pigment, an aluminium pigment or a white interference pigment, both types also mix differently. Blue and green-coloured pigments increase their chromaticity in a mixing series with an achromatic pigment until a turning point, after which chromaticity decreases again. This turning point cannot be observed with yellow and red-coloured pigments. In the mixing series with an achromatic pigment, the chromaticity decreases continuously.

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