Tech
INFO

Equations to calculate color differences and their use in practice

Delta E and Delta E2000

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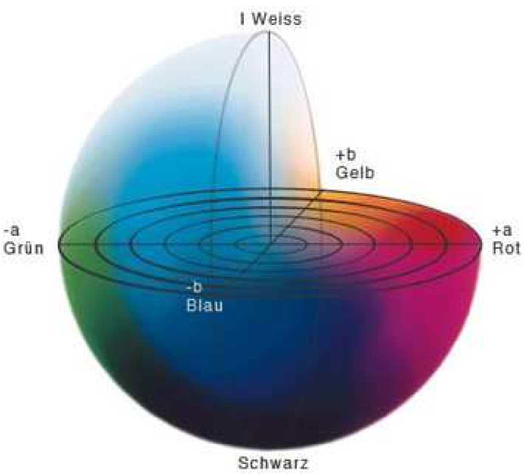
Today, the industry allows minimum tolerances for the replication and printing of colour shades. However, the individual human eye perceives and evaluates colour shades and colour differences.

Using a spectrophotometer, a reference colour can be accurately measured against the sample under a specified light source, irrespective of the individual perception of the human eye and the surrounding area.

In 1976, the International Commission of Illumination CIE (Commission Internationale d'Eclairage) defined the basis for this:
the CIELab colour space.

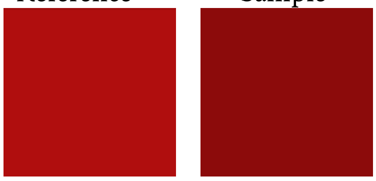


The CIELab colour space is a three-dimensional, spherical model. The L* axis stands for the lightness and goes from White to Black. Absolute White has been defined at L* = 100, while L* = 0 is absolute Black.

The a* axis connects the red area with the green, while the b* axis goes from yellow to blue. The achromatic colours are located in the centre of the sphere. The further a colour shade is located away from the centre, the more brilliant and saturated it is.

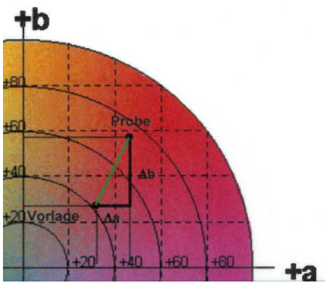
The L*a*b* coordinates, measured with the spectrophotometer, are able to define any colour shade in this system.

Reference   Sample



Reference	Sample
L*= 42,32	L*= 40,02
a*= 46,69	a*= 45,21
b*= 27,14	b*= 23,40

Also in the CIELab System, differences in Lightness DL* (ΔL*), differences in the red /green Da* (Δa*) and yellow/blue Db* (Δb*) can be visualized as well as calculated:



DL* = L* Sample – L* Reference
Da* = a* Sample – a* Reference
Db* = b* Sample – b* Reference

Example:
DL* = 40,02 – 42,32 = -2,3
Da* = 45,21 – 46,69 = -1,48
Db* = 23,40 – 27,14 = -3,73

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Difference in Lightness = DL*
a negative value indicate that the sample is darker while a positive value indicate a lighter sample

Difference in Red – Green = Da*
a negative value indicate that the sample is more greener while a positive value indicates the sample is redder

Difference in Yellow – Blue = Db*
a negative value indicates that the sample is bluer while a positive value indicates the sample as yellower

Therefore, the shown sample is darker, greener and bluer than the reference.

With these single deviations the total color difference Delta E (also DE^*_{ab} or ΔE^*_{ab}) between sample and reference can be calculated:

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

Example:

$\Delta E^*_{ab} = \sqrt{(-1{,}48)^2 + (-3{,}73)^2 + (-2{,}3)^2} = 4{,}62$

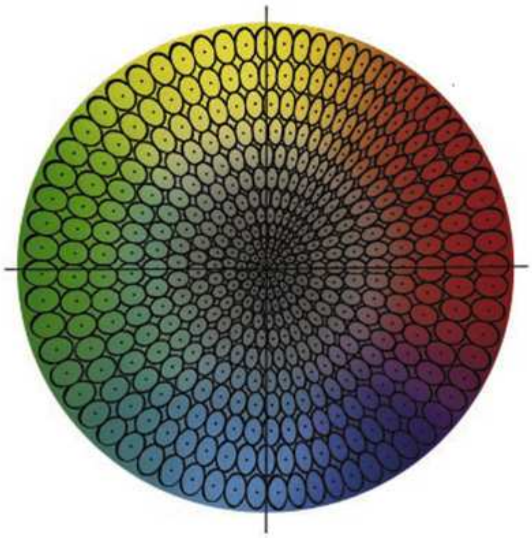
Please note:
The smaller the numerical value, the smaller the colour difference.

The fact that the CIELab system is not visually linear, however, is unfavourable. The calculated colour differences are not the perceived differences.

In practice it means that smallest numerical colour differences in achromatic colours are visible to the human eye; thus, it is absolutely desirable to keep the DE^*_{ab} value as small as possible.
The colour shades that are farthest away from the CIELab centre - the more brilliant and saturated they are - the less visible as colour differences to the human eye.
Therefore, it is possible that the human eye is not able to see a numerically high DE^*_{ab} value.

Generally, differences in colour are perceived more readily than differences in lightness and saturation.

In practice, if you are comparing two achromatic grey shades, a measured DE^*_{ab} value of 2,5 will be perceived as high colour difference, whilst the same numerical value between two brilliant yellow shades is indistinguishable.



DE Tolerance Zone
All shades within one ellipse
seem to be identical to the human eye

The DE^*_{ab} equation has been improved in order to be closer in perception to the human eye.

For this reason, the CMC formula was developed, which is nowadays mainly used by the textile industry. The CIE 94 formula, a further development for the evaluation of small deviations, was unable to provide.

With the current DE2000 formula (also DE^*_{00}, CIEDE2000), much better conformity with visual perception has been accomplished. Unfortunately, the industry hasn't widely adopted this system yet, and consequently it is not integrated in ISO standards such as ISO

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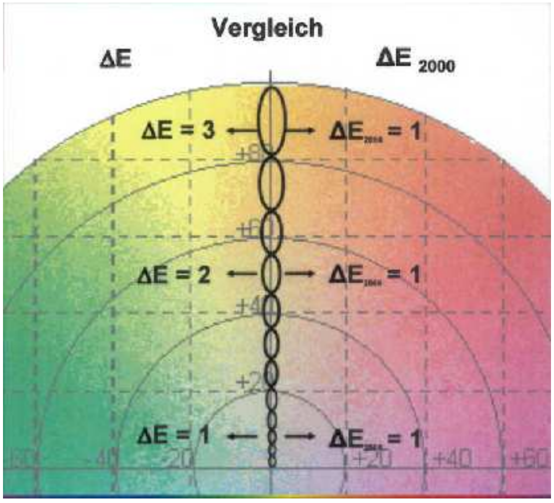
2846 (Colour and transparency of printing ink sets for four-colour printing), ISO 12647-2 (Process control for the production of half-tone colour separations, proof and production prints -- Part 2: Offset lithographic processes) or ISO 12647-5 (Process control for the manufacture of half-tone colour separations, proof and production prints -- Part 5: Screen printing).



In practice, however, the use of the DE2000 equation for the evaluation of achromatic colours, shows almost the same numerical result as if DE^*_{ab} is used. Comparing high saturated colour shades the mathematics of DE2000 influences the numerical value much more, equal to the perception of the human eye.

Resume, and recommendations:

The CIELab colour space is not equidistant enough for practical applications. With highly saturated brilliant colours the difference between two colour shades will be perceived by the human eye smaller than the calculated numerical dE^*_{ab} value would reveal. On the other hand, a small numerical DE^*_{ab} value received by comparing two achromatic colour shades (located close to the centre of the CIELab model) could be a higher colour difference for the human eye. High DE values in one colour area can show a bigger impact than small DE's in another area of colour.

In practice often the same DE^*_{ab} tolerance e.g. < 2,0 is requested – for all colour shades. For high brilliant shades this can be difficult to achieve, yet the same deviation between two shades of grey is likely to result in a claim.

The DE2000 formula currently allows the closest convergence with the visual impression. An appropriate correction takes place dependent upon the CIELab coordinates of the comparative colour shades. In industry, despite the evident shortcomings of the CIELab formula, the DE2000 formula has not really become popular yet - even though more popularity would be desirable!

The Marabu ColorFormulator MCF software provides all the above mentioned equations.

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