CIE R1-57 *Border between Blackish and Luminous Colours*

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At the CIE meeting in Sun City, South Africa, June 2011, CIE Division 1 established the Reportership CIE R1−57 *Border between Luminous and Blackish Colours* with Thorstein Seim (Norway) as the reporter. This was in response to the resolution 18/2009 of ISO/IEC JTC1/SC28.

CIE task:

To study the literature which determines by psycho-physical and physiological experiments, the colour border between luminous and blackish colours in white surrounds.

Introduction

Establishing a border between luminous and blackish colours is important for an understanding of how our visual system works. By giving the CIE coordinates for these colours and the experimental conditions, the current CIE models, describing the visual appearance of colours, can be improved. By examining the literature we will try to summarize the results from experiments which determine the zero greyness/blackness (G0) coordinates and the experimental conditions influencing these coordinates.

Description of concepts

Greyness and blackness

A grey-scale is a scale of achromatic colours, usually a lightness scale between a white and a black sample. For very dark greys the word “blackish” is used. Evans introduced the concept of zero greyness (G0) to describe an achromatic colour in the absence of perceived greyness, but also in the absence of the luminous quality it has when the luminance becomes higher than that of the background. The Natural Color system (NCS) uses blackness, *s*, when they scale grey colours.

Chromaticness

Chromaticness is used by NCS to describe the chromatic strength or saturation of a give hue. It can be compared to Chroma, used in the Munsell System. But while Chroma is scaled for each hue on a perceptual scale, the NCS uses chromaticness, *c*, to describe the relative chroma of a colour, compared to a subjective maximum chroma of 100. In other words, chromaticness is equal to normalized Munsell Chroma.

Optimal colours

Colours with reflectances that changes from zero to one, or from one to zero, at one (or a maximum of two) wavelengths. They represent the optimal (virtual) border of the reflectance spectra of natural colours.

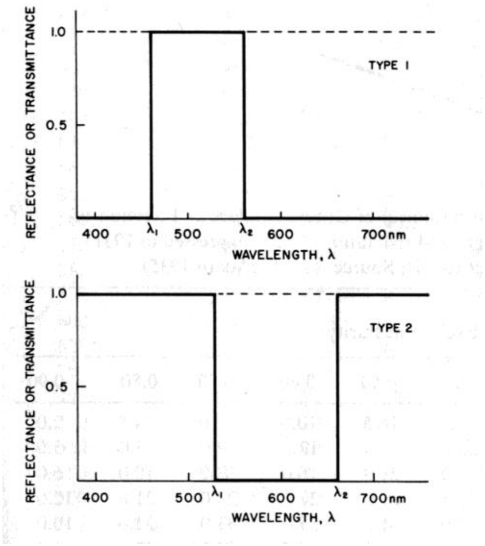

Figure 1.1. Optimal colours

If two optimal colours mix together to white, then they are called antichromatic optimal colours.

Ostwald colours

A special case is when the reflectance of two optimal colours changes at two complementary wavelengths, for example on the line λ_1 (470nm) - D65 - λ_2 (570nm) in the CIE chromaticity diagram. A complementary optimal colour pair with the wavelength limits λ_1 and λ_2, and the limits λ_2 and λ_1 is called an antichromatic pair of two Ostwald colours.

1. Psychophysical experiments

1.1 Evans work

Evans called the border between luminous and blackish colours G0, indicating zero greyness in the test field. He also used the notation “fluorent” for colours of a narrow range of luminances higher than the G0 stimuli (Evans & Svenholt, 1967). Thus the perception of fluorescence (which may be called “fluorence”) characterizes the border zone between greyish and bright colours. On the brighter side, colours simply become brighter (as light sources), but do not look fluorescent.

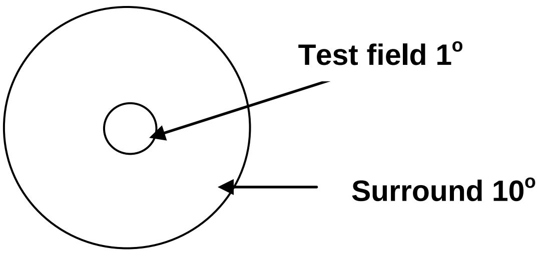

Figure 1.2 Stimulus Configuration: 1° Test Field with variable luminance and constant chromaticity.10° Achromatic Surround with constant luminance of 318 cd/m2. (Heckaman and Fairchild, 2004).

Evans main work was with “related colours” i.e. colours presented in the centre of a surround field, as shown in Fig. 1.2. The 10° diameter surround was normally white, and held at constant luminance. In the 1° diameter test field centre he could place stimuli of variable luminance and different spectral compositions (colours). For each colour he could vary the luminance in order to establish the border between luminous and blackish colour, i.e. where the colour neither contained blackness nor appeared luminous.

His two main studies of G0 colours deal with a) spectral test stimuli and b) desaturated colour stimuli. (Evans and Swenholt, 1967/68).

Saturated colours

The results from using saturated spectral colours are described in the work of Evans and Swenholt (1967). The G0 border was found for 29 stimuli of various dominant wavelengths. They plotted the G0 into a diagram with wavelength as abscissa and the logarithm of L_S/L_T as ordinate, where L_S and L_T are the luminance of the surround and the test field respectively. They found that the G0 response curve closely resembled the colorimetric threshold p_c when plotted as log $1/p_c$. The two parameters were found to be related by a constant multiplicative value.

Desaturated colours

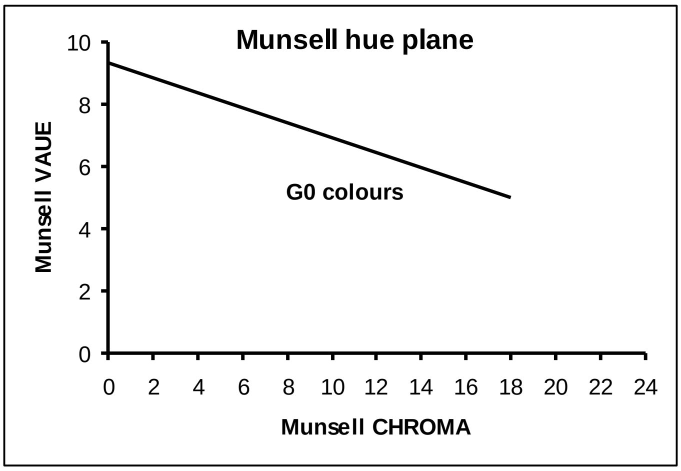

Figure 1.3. Comparing zero grey-content of desaturated test colours with Munsell scaling of Chroma and Value. (Evans and Swenholt, 1968).

For desaturated colours the experimental G0 data of Evans and Swenholt (1968) closely follow a straight line in the Munsell Chroma/Value plane: see Fig. 1.3. However, the Munsell System uses a medium grey adapting surround, not a white, like in their experiment (Fig.1.2). It is well known that changing the adapting background from grey to white significantly changes the Value-scaling.

1.2 The Natural Colour System (NCS)

1.2.1 Experimental conditions

The NCS experiment was performed in a booth painted light grey (ca 56% reflectance). The colour sample was placed on a white surface (surrounded by grey). The observer's task was to evaluate the visual properties of the colour sample. NCS recommend placing colour samples of 40x50 mm size on the white background of A4 size (ca 80% reflectance). Distance to the observer eyes: 0.5m. Illumination: Diffuse (simulated) daylight of 1000 lux.

1.2.2 Achromatic samples:

In this case the observer was asked to evaluate two properties of the sample, its whiteness, *w* and its blackness, *s*. The sum of these two properties was normalized to 100.

1.2.3 Coloured samples:

First the hue was defined, based on the amount of four elementary or unique hues Red, Green, Yellow and Blue. The sample was either defined as one of the four elementary hues, or in-between two elementary hues. If so the observer was asked to evaluate the amount of the two contributions in the sample. The sum of elementary hues was normalized to 100. For example, the NCS hue Y10R is a slightly yellowish hue with 90% yellow and 10% red contribution.

After the hue was defined, the observer was asked to evaluate perceptually three properties of the sample, its chromaticness, *c*, its whiteness, *w* and its blackness, *s*. The sum of these three properties was normalized to 100, assuming that these three qualities gave a complete description of the colour sample. The observers had some problems with establishing the maximum of the chromaticness. This was defined as the most chromatic sample (*c* = 100) the observer could imagine from subjective experience. As a guide the observer was sometimes shown a highly chromatic colour sample, given a tentative c-value.

For establishing the coordinates for zero blackness of chromatic and achromatic colours, the value of *c* is of little importance, since we only need to know the CIE coordinates for the *s* = 00 samples for each hue plane. Only in colour scaling experiments are the relative weights of the *c* = 100 colours of different hues of importance.

1.2.4 Adaptation

The colours with zero blackness s (G0 colours) will change when the adaptive state of the eye changes. In the NCS experiment the white background controls the adaptation. In the Munsell experiment (Judd and Wyszcki, 1967) the background was medium grey, not white. This may change the coordinates (and the CIE values) for colours with zero blackness. The Munsell experiment did not include questions about zero blackness, but Evans made extrapolations from the results of his experiment and placed the G0 colours in the Munsell colour space. See Fig. 1.3.

1.2.5 Normalization

Since the sum of *s* + *w* + *c* = 100 all of the most chromatic samples (*c* = 100) has zero *s* and *w*. We know from Evans experiment that, by adjusting the luminance of the stimulus, the sample can get zero greyness. However, since the NCS system only describes the colour of surface colours, we do not *a priori* know if such a colour is obtainable as a surface colour. In the NCS system the *c* = 100 colours are extrapolated from experimental data, so this question may not have been discussed.

1.3 The DIN 6164 colour system

The DIN 6164 colour system is a German system for colour by the attributes hue *T* (Buntton), darkness step *D* (Dunkelstufe) and saturation *S* (Saettigung). Blackness scaling in this system is called Dunkelstufe. Dunkel-stufe zero is equivalent to NCS zero blackness for antichromatic optimal Ostwald colours. ISO/IEC 15775 uses the symbol *N* (french noir) for Black. Therefore the symbol *n** is used for relative blackness *n** in DIN 33872-1.
The system uses a colour space, limited by the optimal surface colours, which include the Ostwald colours of maximum chromatic value. The Ostwald colours are compared to the NCS colours of zero blackness in Fig. 1.5.

1.4 Other works

A recent study was carried out by Nayatani and Sakai (2006). They found “zero-grayness luminance” (G0) proposed by Evans gives approximately the same perceived brightness for spectrum colours irrespective of hues. They found very close correlation between G0 and metric lightness.

Nayatani et al. have done several studies of the Evans G0 colours. See Literature list.

The spectral G0 values can also be compared with the inverted spectral saturation function. This was done by Hurvich and Jameson (1955), finding a close similarity between the logarithm of colorimetric purity and the logarithm of G0 values presented in a L_S/L_T diagram. This is also found four experimental spectral saturation functions.

The point *G*0 is uniquely determined by the chromatic strength of a colour as represented in a colour order system or appearance space. (Heckaman, R. L. and Fairchild, M. D., (2006).

1.5 CIE based computations of G0

1.5.1 Linear model, describing G0 colours

The YAB formulas
The YAB data specify colours by linear equations and use the CIE tristimulus values *X*, *Y*, and *Z*. The model parameters are included in the figure below:

colour valence metric (color data: linear relation to CIE 1931 data)		
linear color terms	**name and relationship to CIE tristimulus or chromaticity values**	**notes**
tristimulus values	X, Y, Z	
chromatic value red–green yellow–blue radial	*linear chromatic value diagram (A, B)* $A = [\, X / Y - X_n / Y_n \,]\, Y = [\, a - a_n \,]\, Y$ $= [\, x / y - x_n / y_n \,]\, Y$ $B = -\,0{,}4\, [\, Z/Y - Z_n/Y_n \,]\, Y = [\, b - b_n \,]\, Y$ $= -\,0{,}4\, [\, z / y - z_n / y_n \,]\, Y$ $C_{AB} = [\, A^2 + B^2 \,]^{1/2}$	*n=D65* *(background)*
chromaticity red–green yellow–blue radial	*linear chromaticity diagram (a, b)* $a = X / Y = x / y$ $b = -\,0{,}4\, [Z / Y\,] = -\,0{,}4\, [z / y\,]$ $c_{ab} = [\, (\, a - a_n \,)^2 + (\, b - b_n \,)^2 \,]^{1/2}$	*compare to linear cone excitation* ***L*/(*L*+*M*)=*P*/(*P*+*D*)** ***S*/(*L*+*M*)=*T*/(*P*+*D*)**

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Figure 1.4. The YAB formula uses linear transforms of CIE tristimulus values to specify colours, including the G0 colours.

The YAB formula is based on the Luther-Nyberg colour space (Nyberg 1928) which is used in the DIN 6164 colour order system, and by Hurvich and Jameson (1955).

The YAB formula, presented in Fig. 1.4, can be used to compute the blackness in a colour sample. The NCS samples of maximum chromaticness (and zero blackness) are located on the red line between *Y* = 100 and each Ostwald sample of an optimal colour. This is shown in Fig. 1.5 below. The 21 samples of the NCS samples between White and the most chromatic colour are located on the blue line and are the NCS colours with zero blackness (*s* = 00).

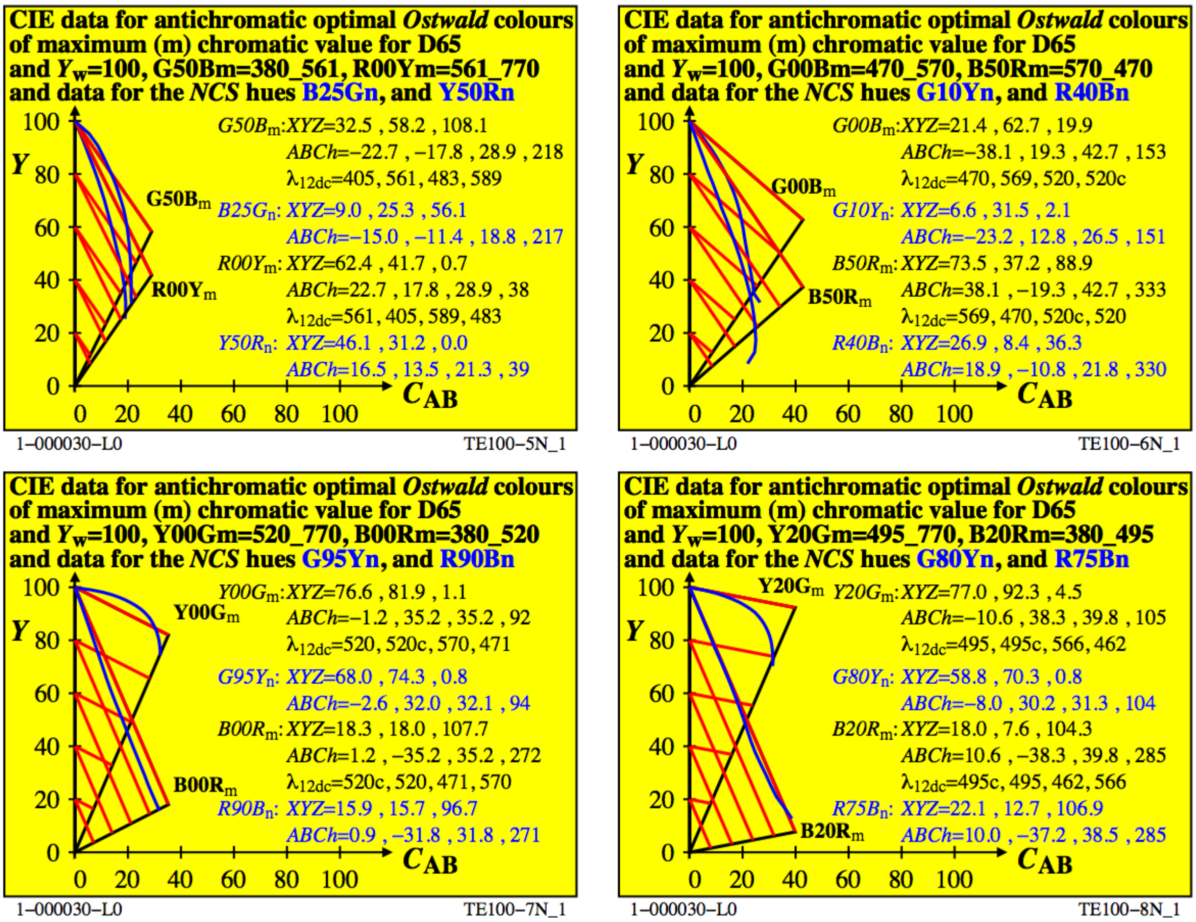

Figure 1.5. Eight Ostwald colours of maximum (m) chromatic value, including the elementary hues R00Y_m, Y00G_m, G00Bm, and B00R_m are shown. Colours of zero blackness are predicted by the red line between White and the Ostwald colours. Eight NCS hues (index n) of zero blackness (s = 00), for example G95Y_n, and R90Bn with approximately the same hue angle h_{AB} compared to Y00G_m and B00R_n (bottom left) are shown.

Fig. 1.5 contains the coordinates of NCS colours with zero greyness (G0), computed by the YAB formula (blue lines) from the Swedish Standard SS 01 91 04. For blackness other than zero the formula assumes that the constant blackness lines will be parallel to that for zero blackness, and that blackness on the Y-axis will be constant along these lines.

Fig. 1.5 bottom/left shows the results for unique yellow Y00G_m and blue B00R_m. The line of zero blackness, computed by the YAB model, is the red line between Y = 100 and hue Y00G_m. The figure top/right contains the unique green G00B_m in the Ostwald system and the purple colour B50R_m. The computed values (red lines) deviate from the NCS coordinates (blue curve), especially for saturated colours. However, the saturated colours (above ca c = 50) are mostly extrapolated values from the experimental data.

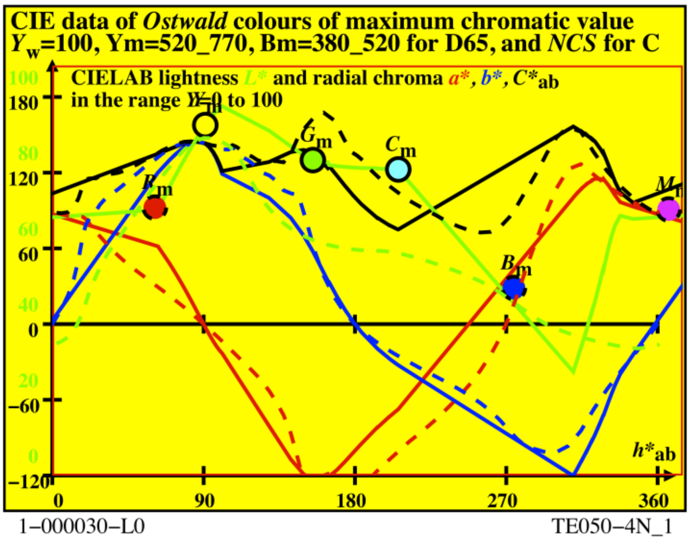

Figure 1.6. A comparison between 3 pairs of Ostwald colours with maximum chromatic value and the 16 maximum chromatic hues in the NCS system. Abscissa: Hue angle h_{ab} in degrees. Black line: Ostwald colours. Dashed black line: NCS c = 100 colours.

Fig. 1.6 shows two types of colour stimuli which are assumed to have zero blackness. The CIELAB data L^*, a^*, b^*, and C^*_{ab} of the Ostwald colours are shown by bold lines and of the *NCS* colours (c = 100, s = 0) by dashed lines. All data are given as a function of CIELAB hue angle h_{ab}. Forty hues of Ostwald colours and 80 hues of NCS colours of the Swedish Standard have been used to make this figure. All NCS values are extrapolated values from the experimental data. Both the (extrapolated) NCS colours and the computed Ostwald colour coordinates are assumed to have zero blackness, but some deviations between the two curves are seen in the figure.

The black scale on the ordinate is for the CIELAB coordinates red-green chroma a^* (in red), yellow-blue chroma b^* (in blue), and radial chroma C^*_{ab} (in black). In addition, the green scale in the ordinate is for the CIELAB lightness L^* which shows larger deviations (in green).

1.6 The sRGB standard, IEC 61966-2-1

This colour standard uses three device primary colours *RGB* which add to three mixture colours CMY and intermediate colours. An additive mixture of three primary colours produces all colours of the sRGB colour space. The coordinates of these primary and mixture colours are roughly similar to the Ostwald colours.

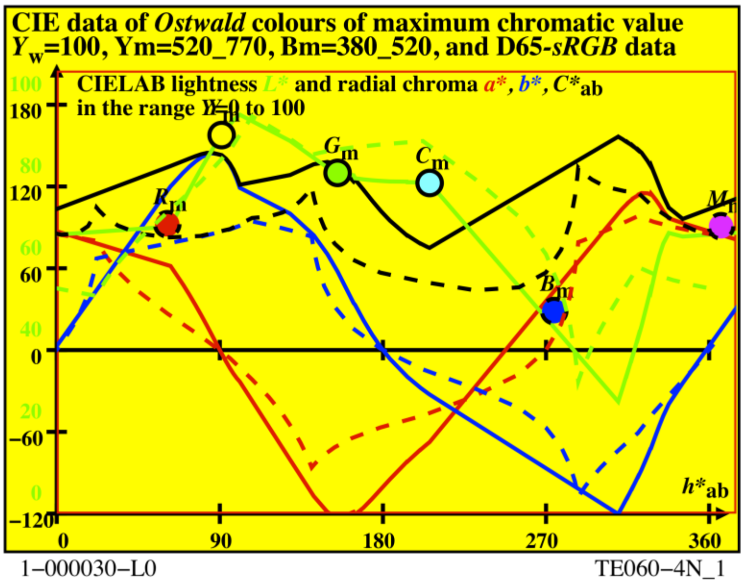

Figure 1.7

Fig. 1.7 shows two types of colour stimuli which are assumed to have zero blackness. The CIELAB data *L*, a*, b**, and C^*_{ab} of the *Ostwald* colours are shown by bold lines and of the *sRGB* colors according to IEC 61966-2-1 by dashed lines. This Standard defines three primary colours Red (R), Green (G), and Blue (B). The additive mixture leads to Yellow (Y = R+G), Cyan (C = G+B) and Magenta (M = B+R), and intermediate colours. All data are given as a function of CIELAB hue angle h_{ab}. Forty hues of Ostwald colours and 48 hues of sRGB colours with maximum chromatic value have been used to make this figure. The Ostwald colours are assumed to have zero blackness. The sRGB colours show larger deviations compared to Fig. 1.6 between the bold and dashed curves.

The black scale in the ordinate is for the CIELAB coordinates red-green chroma *a** (in red), yellow-blue chroma *b** (in blue), and radial chroma C^*_{ab} (in black). In addition the green scale in the ordinate is for the CIELAB lightness *L** (in green).

The colour gamut of the Ostwald colours includes all (non-fluorescent) surface colours. It may be a goal of a display designer to produce all the Ostwald colours by three or more primaries. Then the display colour output matches all possible surface colours for any hue described by the bold lines in both Fig. 1.6 and 1.7.

1.6.1 Colour coordinates of Ostwald colours of blackness n = 0*

rgb^*_e and CIE data of a elementary hue circle according to CIE R1-47 for *Ostwald* colours
XYZ, xy, YAB,* and *Lab** data for relative spacing of elementary hue h_{ab} of *CIELAB
16 step elementary hue circle with intended elementary hues: h_{ab} = 25.4, 92.3, 162.2, 271.7 of CIELAB

	X	Y	Z	x	y	A	B	C_{AB}	h_{AB}	L^*	a^*	b^*	C^*_{ab}	h_{ab}	$rgb \to rgb^*_e$
R00Y=R	66.0	41.1	20.9	0.515	0.321	26.9	9.5	28.5	19.5	70.3	70.9	33.4	78.4	**25.2**	**1.00 0.00 0.00**
R25Y	64.0	41.5	6.4	0.571	0.371	24.5	15.5	29.0	32.3	70.5	65.1	71.4	96.6	**47.6**	**1.00 0.25 0.00**
R50Y	62.6	41.7	1.0	0.593	0.396	22.8	17.7	28.9	37.8	70.7	61.2	106.3	122.7	**60.0**	**1.00 0.50 0.00**
R75Y	71.1	58.7	0.1	0.546	0.451	15.3	25.5	29.7	59.0	81.1	35.2	137.3	141.7	**75.6**	**1.00 0.75 0.00**
Y00G=Y	76.8	83.9	1.3	0.473	0.517	−2.9	36.0	36.1	94.7	93.4	−5.9	141.9	142.0	**92.3**	**1.00 1.00 0.00**
Y25G	65.9	89.6	6.7	0.406	0.552	−19.2	36.3	41.1	117.8	95.8	−39.4	113.6	120.3	**109.1**	**0.75 1.00 0.00**
Y50G	43.7	79.6	8.1	0.332	0.605	−31.9	31.4	44.7	135.4	91.5	−77.3	101.2	127.3	**127.3**	**0.50 1.00 0.00**
Y75G	26.4	67.7	12.4	0.247	0.635	−38.0	24.5	45.2	147.1	85.9	−113.0	78.6	137.7	**145.1**	**0.25 1.00 0.00**
G00B=G	21.8	61.8	31.6	0.189	0.536	−36.9	14.2	39.5	158.8	82.8	−119.5	37.9	125.4	**162.3**	**0.00 1.00 0.00**
G25B	27.8	58.9	81.5	0.165	0.349	−28.1	−6.9	28.9	193.9	81.2	−86.9	−13.9	88.0	**189.1**	**0.00 1.00 0.50**
G50B	25.6	45.4	108.7	0.142	0.252	−17.5	−23.7	29.5	233.5	73.1	−61.3	−46.1	76.7	**216.9**	**0.00 1.00 1.00**
G75B	20.2	29.3	108.4	0.128	0.185	−7.6	−30.6	31.5	256.0	61.0	−33.4	−66.8	74.7	**243.4**	**0.00 0.50 1.00**
B00R=B	18.4	18.7	107.7	0.127	0.129	0.6	−34.9	34.9	271.0	50.4	3.3	−84.8	84.9	**272.2**	**0.00 0.00 1.00**
B25R	18.0	8.8	105.2	0.136	0.067	9.5	−38.2	39.4	284.0	35.7	64.2	−108.5	126.1	**300.6**	**0.50 0.00 1.00**
B50R	61.7	26.3	99.4	0.329	0.14	36.7	−28.3	46.3	322.3	58.3	112.5	−65.8	130.3	**329.6**	**1.00 0.00 1.00**
B75R	71.2	40.6	51.0	0.437	0.249	32.5	−2.6	32.6	355.2	69.9	83.6	−7.1	83.9	**355.1**	**1.00 0.00 0.50**

5 step equidistant grey scale with intended lightness: L^* = 0.0, 25.0, 50.0, 75.0, 100.0

	X	Y	Z	x	y	A	B	C_{AB}	h_{AB}	L^*	a^*	b^*	C^*_{ab}	h_{ab}	$rgb \to rgb^*_e$
N000W=N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**	0.0	0.0	0.0	0.0	**0.00 0.00 0.00**
N025W	4.1	4.4	4.8	0.312	0.329	0.0	0.0	0.0	77.5	**25.0**	0.0	0.0	0.0	0.0	**0.25 0.25 0.25**
N050W	17.5	18.4	20.0	0.312	0.329	0.0	0.0	0.0	55.3	**50.0**	0.0	0.0	0.0	0.0	**0.50 0.50 0.50**
N075W	45.8	48.2	52.5	0.312	0.329	0.0	0.0	0.0	21.0	**75.0**	0.0	0.0	0.0	0.0	**0.75 0.75 0.75**
N100W=W	95.0	100.0	108.8	0.312	0.329	0.0	0.0	0.0	0.0	**100.0**	0.0	0.0	0.0	0.0	**1.00 1.00 1.00**

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Table I. The coordinates of the *Ostwald* colours for a 16 step elementary hue circle and a 5 step grey scale.

The *Ostwald* colours have the maximum chromatic value of all surface colours and zero blackness. The CIE data *XYZ, YAB, L*a*b** are calculated for the elementary hue angles h_{ab}=26, 92, 162, 272 according to CIE R1-47. These four hue angles are specified by the rgb^*_e coordinates (1 0 0), (1 1 0), (0 1 0), and (0 0 1). In addition there are *Ostwald* colours for three intermediate hue angles, rgb^*_e data and CIE data between these elementary hue angles.

The coordinates listed in Table I corresponds to Fig. 1.6 which shows that the CIE data of the *Ostwald* and the *NCS* colours are similar.

There are many device dependent *RGB* colour spaces with coordinates, *rgb*. The *sRGB* colour space is defined by device dependent rgd_b coordinates and produces the hue angles h_{ab} = 40, 103, 136, and 305 of the *sRGB* device (d) for the values rgb_d = (1 0 0), (1 1 0), (0 1 0), and (0 0 1).

The visual device-indpendent *RGB**e colour space uses the coordinates *rgb**e. The elementary (e) colours are defined visually. The four elementary colours Red R_e, Yellow Y_e, Green G_e, and Blue B_e have the values *rgb** = (1 0 0), (1 1 0), (0 1 0), and (0, 0 1).

For more information of the device and/or elementary colour output with different relative blackness n^* and relative chroma c^*, see the booklet: http://130.149.60.45/~farbmetrik/color.

It is intended by ISO TC159/SC4/WG2 *Ergonomics Visual Display Requirements* (See CIE R1-47) that the values rgb_{*e} produce the four elementary hues and according to the table of the *Ostwald* colours of these elementary hues.

If this is done, than the colours of blackness $n^* = 0$ are produced. The colours of blackness zero are described by the equation

$$n^* = 1 - max\ (rgb_e)$$

Among surface colours all rgb^*_e data are in the range from 0 and 1. For example, elementary Red R_e, Black N, and White W is produced by the rgb^*_e coordinates (1 0 0), (0 0 0,) and (1 0 0). Because of the linear equations in CIELAB space, the colours in the middle between Black N or White W, and Red R_e have the coordinates (0,5 0 0) and (1 0,5 0,5).

For each hue the colours are presented within a triangle. For example, for the elementary (e) hue Red R_e all surface colours are found within a triangle with the corners Black, White and the *Ostwald* colour Red R_e. The visual device independent rgb^*_e system in CIELAB is defined by linear equations between the CIELAB coordinates $(L^*, C^*_{ab})_e$ of the Table and the rgb*e coordinates. There are hundreds of device dependent *rgb* coordinates. However, rgb^*_e is device-independent and based on visual properties, for example zero blackness and chromatic value of the *Ostwald* colour.

1.7 Database

For further CIE work a database with CIE coordinates for colours with zero blackness is under development. This database is collected on the website of the Berlin University of Technology, Germany. See the link:
http://130.149.60.45/~farbmetrik

For the data of the 80 step *NCS* hue circle (*s* = 00) of maximum chromaticness (*c* = 100), and the 21 step grey scale, see the link:
http://130.149.60.45/~farbmetrik/TE03/TE03L0NP.PDF

For the data of the 20 step scales (*s* = 00) between White and the colour of maximum chromaticness (*c* = 100) for the four elementary hues R, B, G, and Y, see the link:
http://130.149.60.45/~farbmetrik/TE11/TE11L0NP.PDF

The database will be expanded when more data are available.

2. Neurophysiological experiments

2.1 Possible neural correlate for zero greyness of achromatic colours

A border between colours containing greyish and fluorent properties may be sought in signals from visual neurons in the retina, the lateral geniculate nucleus (LGN) and the Cortex. Two main cell types, here called the Increment- and the Decrement cells and corresponding to the ON and OFF cells, seem to play an important role in setting up a system for colour and light discrimination and detection. Below we report results from experiments on macaque monkeys and compare them with the results from psychophysical experiments on humans (Valberg and Seim, 2008).

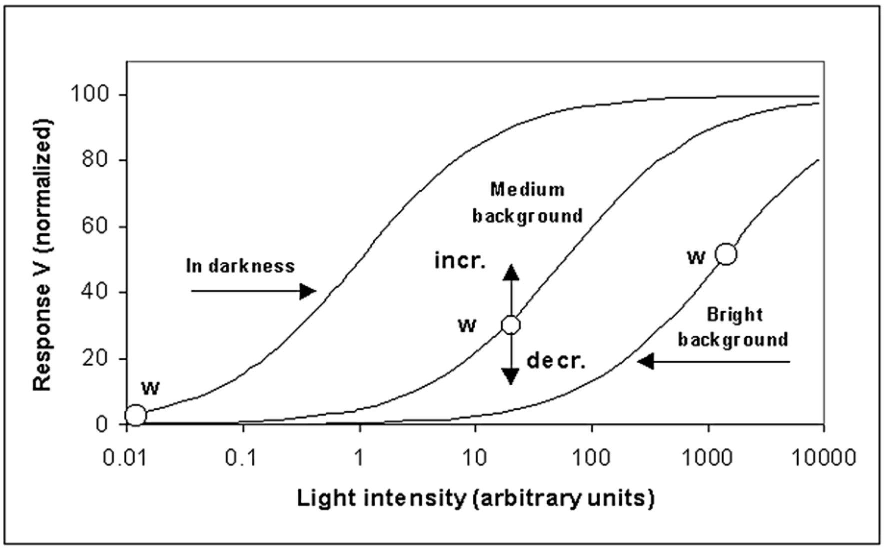

Figure 2.1. The (normalized) response of a cone to light variations.

Fig. 2.1 shows how the light-sensitive receptors (cones) react when adapted to darkness, medium background lightness and a bright background. For a dark background the receptors respond to increments of light intensity, but they respond to both increments and decrements of light when adapted to a higher background luminance, *W*.

At the ganglion cell level the cone signal is split in two, relative to the adapted state (*W*). This is done by two types of ganglion cells: ON- or increment cells and OFF- or decrement cells.

The cells coding for colour are called opponent cells. Each type receives an excitatory input from one cone type, for example the M cone, while it receives an inhibitory input from the L cones. A typical M–L opponent Decrement cell is shown in Fig. 2.2.

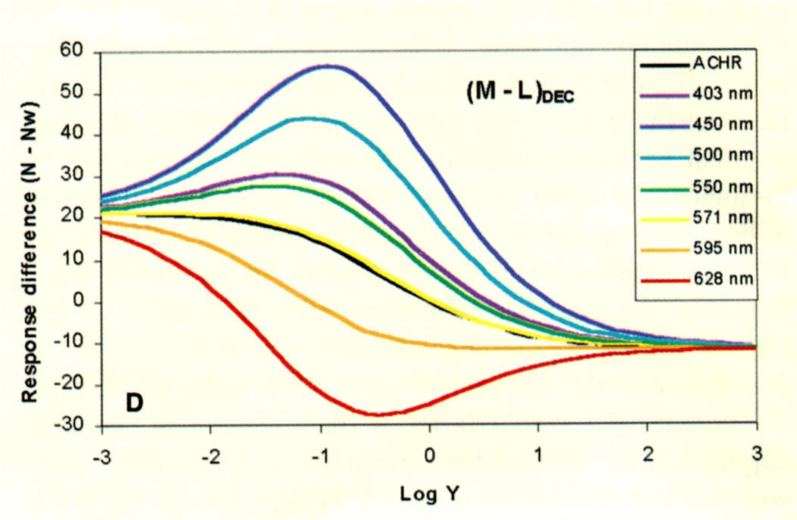

Figure 2.2. The (idealized) response of an opponent (M-cone minus L-cone) Decrement-cell in the macaque monkey.

This hypothetical cell responds to different spectral lights (coloured curves), but it also responds to achromatic light (black curve).

It has been shown that the achromatic signal can be obtained (extracted) by adding signals from different opponent cell types (Valberg and Seim, 2008). An example is shown in Fig. 2.3. Here the thick black curve is the extracted achromatic response from Decrement cells. This response is compared to the scaling of NCS blackness (circles). The maximum blackness (*s* = 100) is multiplied by a constant of 0.27 in order to compare it with the extracted achromatic response. NCS zero blackness is placed in the origin (0,0) of the figure.

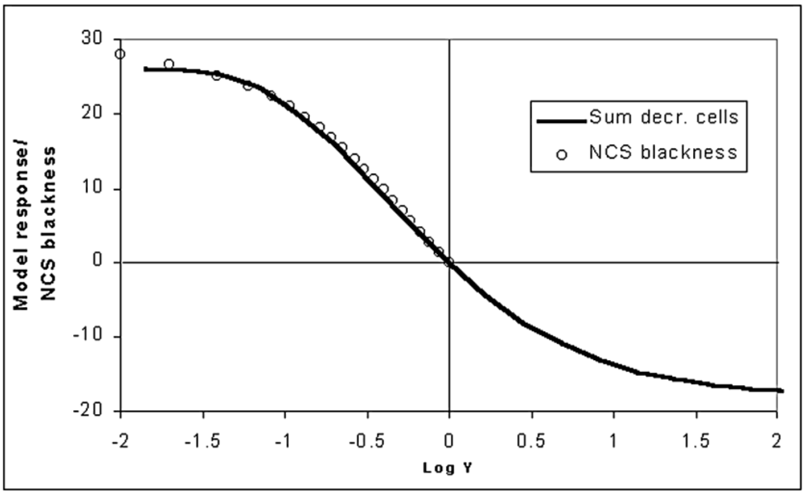

Figure 2.3. Comparing extracted Decrement cell responses to achromatic colours with NCS blackness, *s*. The s-scale is multiplied by 0.27 (circles) in order to compare it with the neural response.

We have shown (Seim et al., 2011) that the negative cell responses in Fig. 2.3 (and Fig. 2.4 below) are removed when the ganglion cell responses are transferred to the LGN (and to the cortex), thus avoiding overlap between the increment (ON) and decrement (OFF) responses.

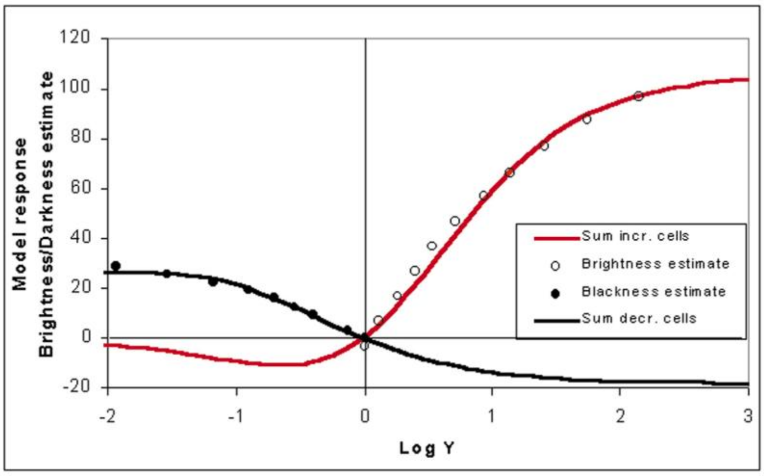

Figure 2.4. Comparing scaling of lightness and blackness (experimental data published by Glad et al., 1976) with Increment cell responses and Decrement cell responses (Valberg and Seim, 2008).

In Fig. 2.4 we compare visual scaling of both blackness and lightness with the extracted achromatic response for decrement (black curve) and increment cells (red curve). Again the visual responses closely follow those obtained from increment and decrement cells.

The crossing of the two curves in Fig. 2.4 is the origin (0,0) and we may assume that this represent the zero blackness (G0) point, as we demonstrated for NCS grey-scaling in Fig. 2.3.

3. Further work

Based on this Reportership Report R1-57 a new CIE Technical Committee is proposed:

Terms of Reference:
Scaling of blackness for chromatic surface colours and display-colours in surface colour-mode.

Suggested studies:

3.1 Further studies of greyness/blackness scaling. More quantitative experiments under specified centre/surround conditions. Criterion: neither fluorent nor grayish.

3.2 Comparing the normalized chromaticness coordinates in NCS with visual scaled colours, in particular the most saturated colours. The relationship between G0 and optimal colours should be investigated.

3.3 Transforming XYZ to new CIE standardized cone absorptions and modify the linear models, for example, the YAB-model. When models based on cone opponent responses are developed, the result can be re-computed to the (new) CIE XYZ coordinates.

3.4 Relationships between neural responses, containing both chromatic and achromatic signals, and perceived chromatic colours with achromatic (blackness or fluorent) contents.

The chromatic information is coded by the opponent parvocellular and koniocellular cells of the LGN. These cells appear to “split” the input signal from cones in two parts by two cell-types: the Increment-cells and the Decrement-cells. Since the light and dark achromatic signals are necessarily coded by the same retinal cells, these percepts need to be subtracted at a later stage to create the achromatic colours. This means that the Decrement cells contain both a chromatic correlate and a greyness/blackness component. In a similar way the response of Increment cells contain both a luminous component and a chromatic correlate. Based on this duality of visual properties we may assume that I-cells, which are coding for increments in chromaticness, also contain a luminous, or fluorent component of the stimulus. Decrement-cell activity may relate to the greyness (or degree of blackness) of the chromatic colours. G0 may correspond to the crossing point (or balance point) on the relative luminance scale.

Since the opponent coding of visual cells both include chromatic and achromatic information, there must necessarily be a balance between the perceived blackness and fluorent components observed. This idea can easily be transformed to specific neurophysiological hypotheses that, in turn, can be developed to become the subject of psychophysical experiments.

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NCS colour standards are available from the Swedish Institute of Standards:
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SVENSK STANDARD SS 01 91 04