Colour Topics in the CIE and Applications

http://farbe.li.tu-berlin.de/_DfwGD_19.PDF or http://farbe.li.tu-berlin.de/_DfwGE_19.PDF

1. Summary

The International Commission on Illumination (CIE) publishes Technical Reports and Standards in the Division 1 *Colour and Vision* and in the Division 8 *Image Technology.* Results of the last four years were shown during the last CIE meeting in Washington 2019 and trends were discussed.

Meeting of the CIE Division 1 *Colour and Vision*

About 40 participants represent 20 member countries of the CIE Division 1. This is leaded since 2015 by Mrs. *Kwak* (Korea). The next meeting is scheduled in Hongkong im April 2020.

During the last four years two new CIE joint committees for new Technical Reports were created:

JTC-16 (D1/D8) *Validity of chromatic adaptation*.

JTC-17 (D1/D2/D8) *Gloss measurement and gloss perception: A framework for the definition and standardization of visual cues to gloss*.

Four Technical Reports in the colour area were published:

CIE 230:2019 Validity of Formulae for Predicting Small Colour Differences,

CIE 015:2018 Colorimetry, 4th Edition.

CIE 224:2017 CIE 2017 Colour Fidelity Index for accurate scientific use.

CIE 217:2016 Recommended Method for Evaluating the Performance of Colour-Difference Formulae.

Meeting of the CIE Division 8 *Image Technology*

Under the leadership of *Po-Chief Hung* (USA) the following Technical Report was published:

CIE 223:2017 Multispectral Image Formats.

Remarks:

The Reportership Report CIE R8-09:2015 *Output Linearization Methods for Displays and Printers* which was developed *K. Richter* as Reporter and contributions of members of six countries, is an internal CIE document and only available for members of CIE Division 8. The ISO application is described in section 3 of this paper.

The Division 1 does not show any more the ISO Liaison Committees on the CIE web site. This web site includes until 2018 links to public Reportership Reports, for example to CIE R1-47 *Hue Angles of Elementary Colours* and R1-57 *Border between Luminous and Blackish Colours* of *Thorstein Seim* (Norwegen). These links were deleted on the CIE web site. Figure 15 shows links for the further accessibility and applications, for example in existing DIN and ISO Standards.

2. Special report about validity of colour difference formulae

CIE 230 deals with the validity of colour difference formulae which are based on the results of experiment to evaluate colour differences visually. The report addresses small colour differences of adjacent colours. Visual evaluations (ΔV) are compared with calculated colour differences (ΔE) using five colour difference formulae: CIELAB, CMC, LABJND, CIE94, and CIEDE2000. A power-function (PF) correction of these formulae is included. The STRESS index is used for the test of the validity of colour difference formulae without and with the power-function correction.

In addition to the COM data set used for the development of the CIEDE2000 formulae, nine new datasets are used in this report (with particular emphasizing colour differences below 2 CIELAB units). The 13 datasets can be downloaded from the CIE web site, see http://files.cie.co.at/TC181_Datasets.zip

Compared with the original formula CIEDE2000 without a power-function the formula CIEDE2000 with a power-function (CIEDE2000_PF) shows the better performance. By this reason CIE 230 recommends the formula CIEDE2000_PF for the prediction of colour differences in the range 0,0 to 5,0 CIELAB units. The LABJND colour-difference formula with the power-function correction (LABJND_PF) gives also good results for visual datasets with average colour differences below 1,0 CIELAB units.

The LABJND formula *K. Richter* (1985) is based on the logarithmic *Weber-Fechner* law for adjacent colours. The CIELAB formula uses the *Stevens* power law with the exponent1/3. The CIELAB formula was originally developed for colour samples locating separate on a gray background. The CIEDE2000 formula and all other formulae are modifications of the CIELAB formula, see for example many colorimetric formulae in the book.

http://farbe.li.tu-berlin.de/BUA4BF.PDF

The interest for work on documents of the CIE-Divisions 1 and 8 has reduced a lot. Until the year 2011 often 20 or more members participate on technical meetings,. However in Washington often only a few participate.

For example after the unanimous vote of the CIE CD by members of five countries in 2015 the publication of CIE 230:2019 takes 3 years instead of some month as described in the CIE Code of procedure (CoP). The reason are in my view:

1. the long response time of CIE members (up to 16 instead of 4 weeks).
2. the long response time of the CIE CB (up to 7 instead of 2 month).
3. in addition the requested unanimous vote of the CIE CB after the unanimous CD vote in 2015.
4. the CIE CB does not accept EPS vector graphics (as ISO and DIN) in the colour field.

Based on these difficulties the further work on a Working Draft (2015) of CIE TC1-63 about the validity of colour difference formulae for large colour differences was stopped.

The Reportership Report CIE R8-09:2015 *Output Linearization Methods for Displays and Printers* has contributed to the standard ISO 9241-306:2018 (60 pages) for the display output at work places. The technical content of CIE R8-09 is available for free download in the internet, see

http://farbe.li.tu-berlin.de/OUTLIN16_01.PDF

In the following the application of CIE R8-09 in ISO 9241-306 described. This ISO standard for the display output at the workplace uses in addition the elementary colour output of CIE R1-47.

3. Introduction display output

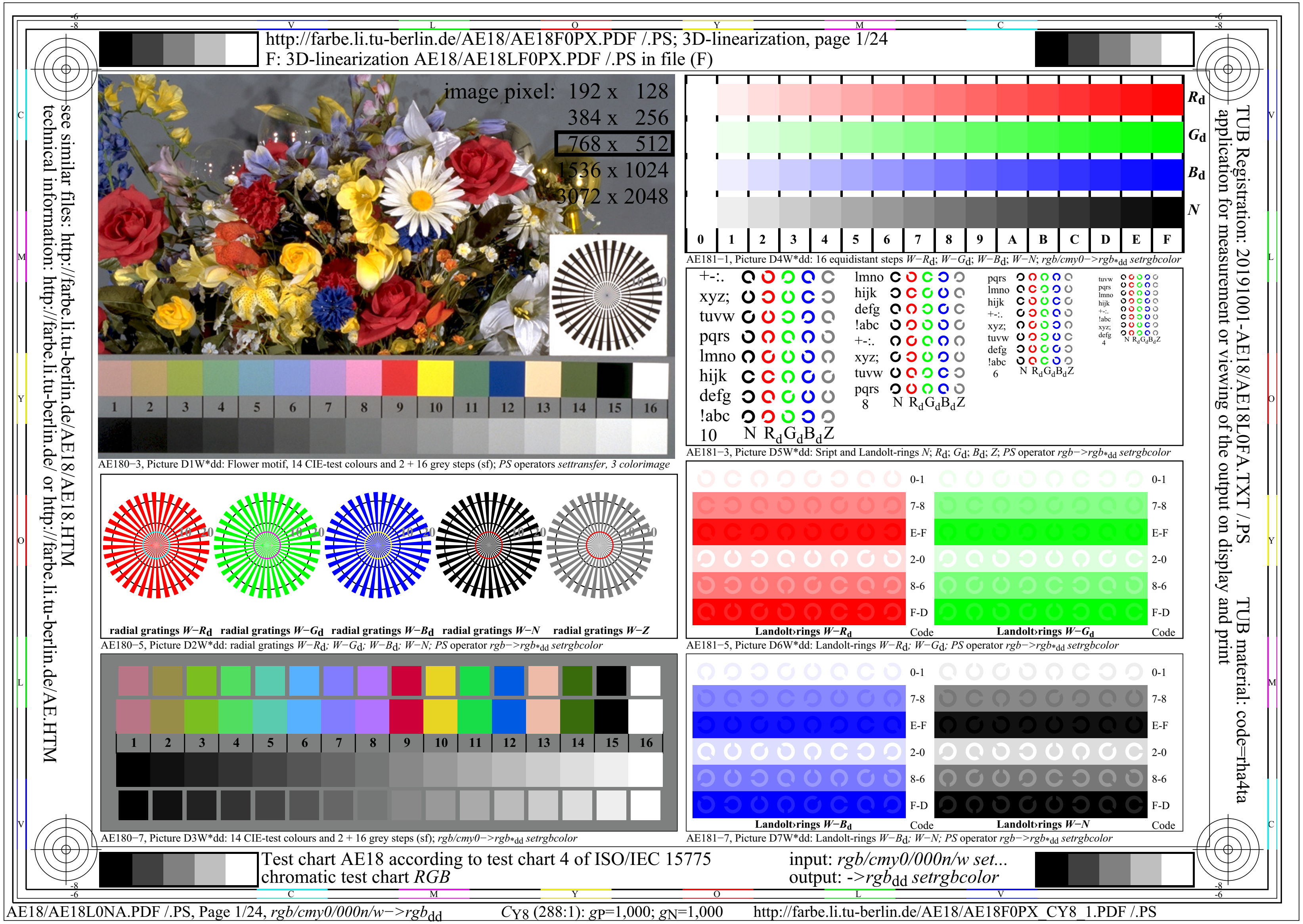


Figure 1: Display output similar to the chromatic test chart AE18 of ISO 9241-306

Figure 1 shows above an URL for the download of this test chart for eight contrast conditions.

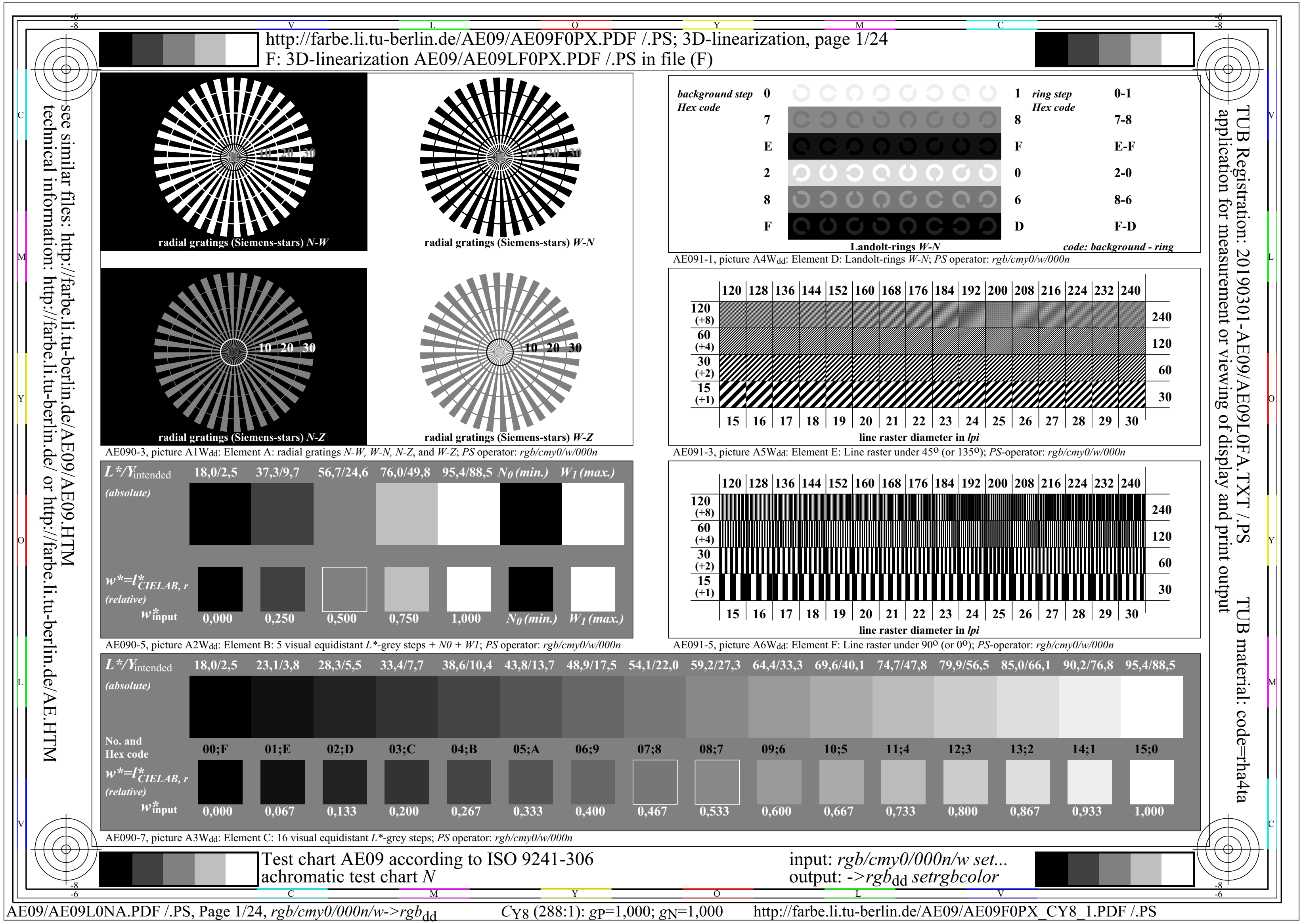


Figure 2: Display output similar to the achromatic test chart AE09 of ISO 9241-306

Figure 2 shows the URL for the download of this test chart for eight contrast situations. Only one of these eight pages usually solves the requirement for the discrimination of all 16 gray steps.

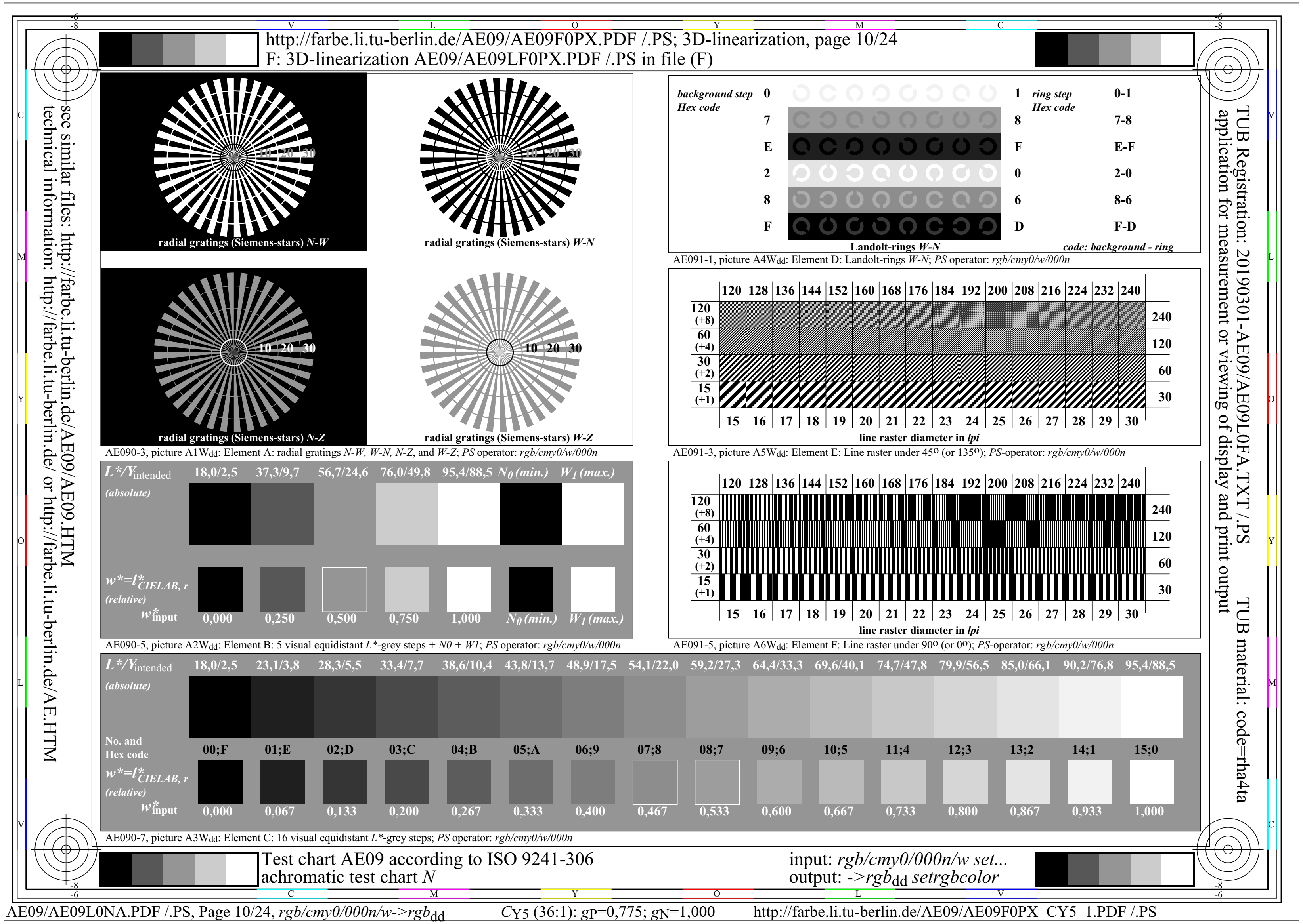


Figure 3: Display output similar to the achromatic test chart AE09 of ISO 9241-306

The here shown page usually shows an equal discriminability of all 16 gray steps for about 2,5% reflection on the display by the environmental light in the office at the work place.

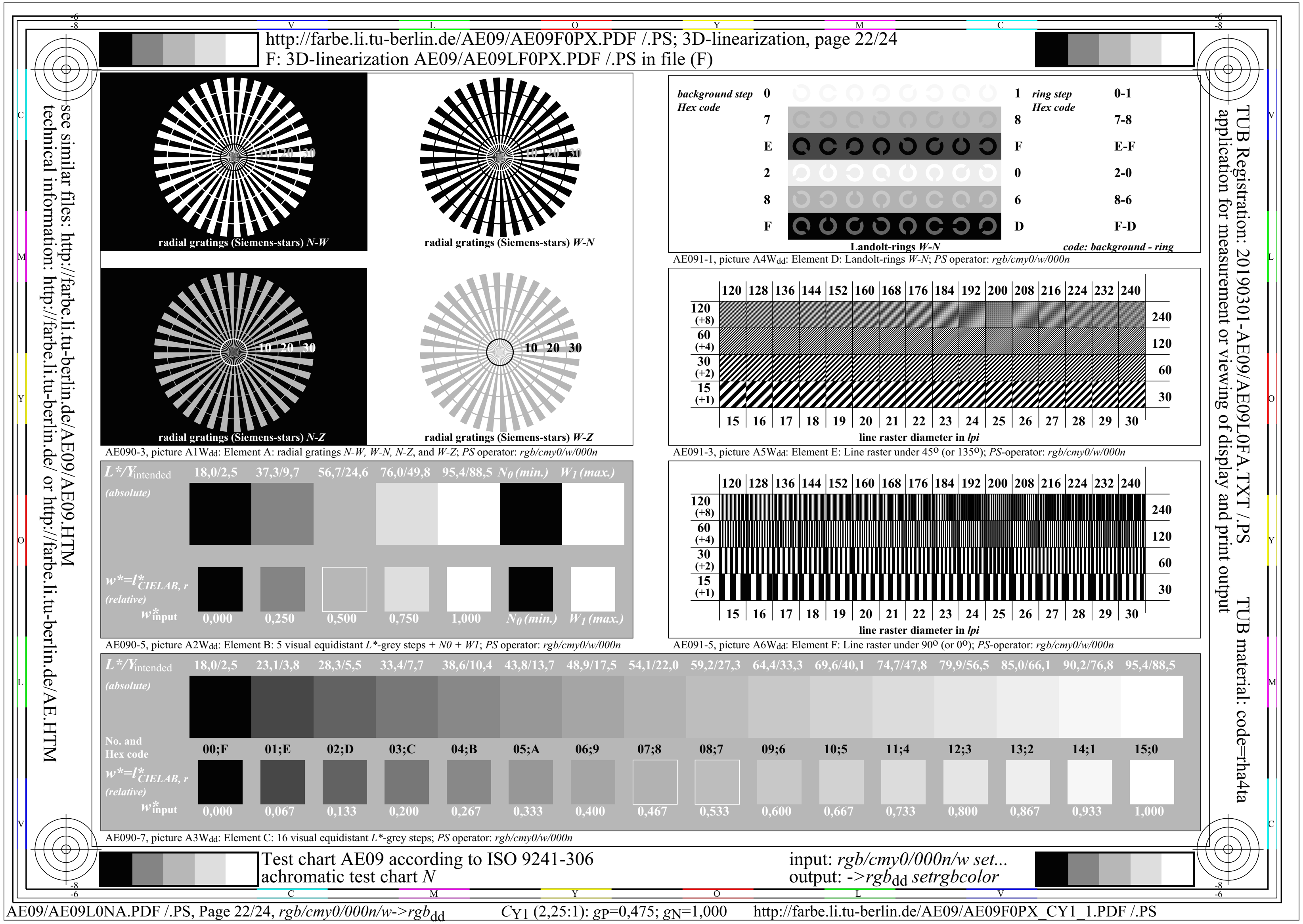


Figure 4: Display output similar to the achromatic test chart AE09 of ISO 9241-306

This page usually shows an equal discrimination of all the 16 gray steps, if for example for data projectors the luminance of both the projector and the daylight is equal at the display.

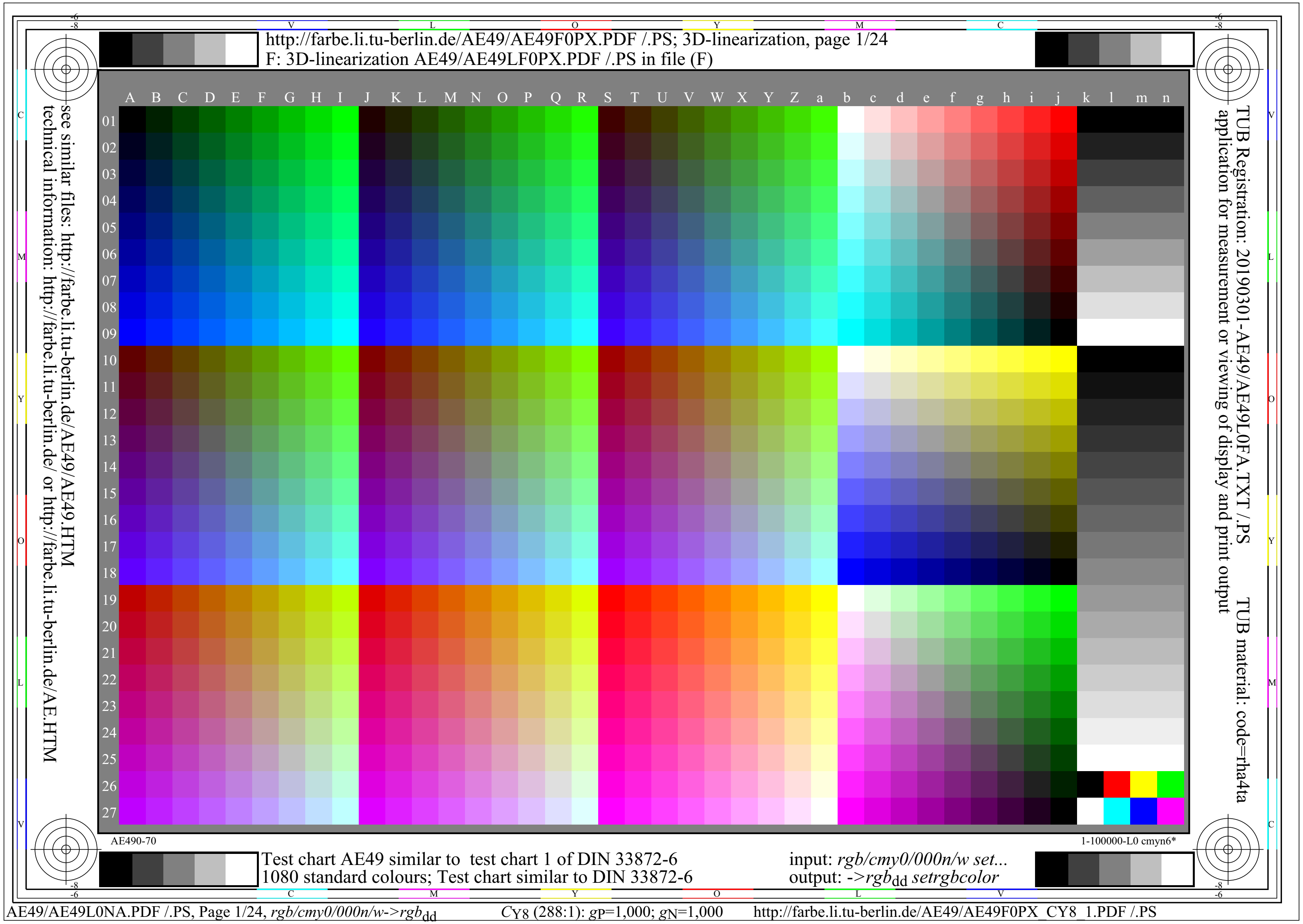


Figure 5: Display output similar to the chromatic test chart AE49 of ISO 9241-306

Figure 5 shows 729 (=9x9x9) colours with equal relative steps, 243 colours of opponent hues, 9 and 16 steps gray scales as well as eight basic colours all with special output goals.

4. Contrasts at the display work place in the office and for data projectors

Contrast step C_{Yi}, see ISO 9241-306[1)]		
Contrast step C_{Yi} (i=1 .. 8) and Y ratio C_{Yi} $Y_W : Y_N$	**CIE tristimulus value; ratio for White W and Black N $Y_W : Y_N$**	**Paper (S) luminance[1)]; ratio [cd/m^2] $L_{WS} : L_{NS}$**
C_{Y8} 288 : 1	88,9 : 0,31	142 : 142/288
C_{Y5} 36 : 1	**88,9 : 2,50**	**142 : 142/36**
C_{Y1} 2,25 : 1[1)]	88,9 : 40,0	142 : 142/2,25

1) http://standards.iso.org/iso/9241/306/ed-2/index.html

EE840−1N

Digital rgb_d exponent transformation and measurement data of three display outputs				
ISO colours in A049 Name	**position**	**page 1 C_{Y8}=288:1 $(r, g, b)^{1,000}$**	**page 4 C_{Y5}=36:1 $(r, g, b)^{0,775}$**	**page 8 C_{Y1}=2,25:1 $(r, g, b)^{0,475}$**
white W	***(01,b)***	1,00 1,00 1,00	1,00 1,00 1,00	1,00 1,00 1,00
Light red R_{Wd}	***(01,f)***	1,00 0,50 0,50	1,00 0,58 0,58	1,00 0,72 0,72
Red R	***(01,j)***	1,00 0,00 0,00	1,00 0,00 0,00	1,00 0,01 0,00
Dark red R_{Nd}	***(05,j)***	0,50 0,00 0,00	0,58 0,00 0,00	0,72 0,01 0,01
Black N_d	***(09,j)***	0,00 0,00 0,00	0,00 0,00 0,00	0,01 0,01 0,01

A software or hardware *Raster-Image-Processor (RIP)* changes the *(r, g, b)* data of page 1 by an exponent *n* for the display output. Eight exponents are used in the ISO file:
http://standards.iso.org/iso/9241/306/ed-2/AE49/AE49F0P0.PDF

EE851−1N

Figure 6: Three contrast steps and the change of *rgb* data by different gamma values.

On the left the table shows three of eight contrast steps CY8, 5, and 1 for the display output. *On the right* the change of *rgb* data by a power function with three different exponents is shown. This change is required for the intended equal discriminability of the gray and colour steps.

The following Figure 7 is a partial output (columns *b* to *n*) of Figure 5.

The *left* part of Figure 7 shows the intended output (only *rgb* file data are used).

The *middle* part of Figure 7 shows the output of an equivalent *PS* file instead of the *PDF* file with the software *Mac Preview*. *Adobe Distiller* gas an option *smoothing (Yes/No)*. For *Mac Preview* this option is missing and *smoothing* is the default, see the smoothed middle part of Figure 7 which includes in addition artifacts by the smoothing.

Also the *right* part of Figure 7 shows a partial output of Figure 5, which includes 1080 colours. To a high degree the colour problem is based on the used *Anticopy Software* which is not compatible with the *EPS* vector graphic of *Adobe.* However, EPS files have been used since 20 years in standard documents. The example was produced in a standard document workflow. In my view this property now stops the revision and new standardization in the area of colour, if for example vector graphic is required for the recognition of colours.

5. Problems of colour output and of affine colour transformations

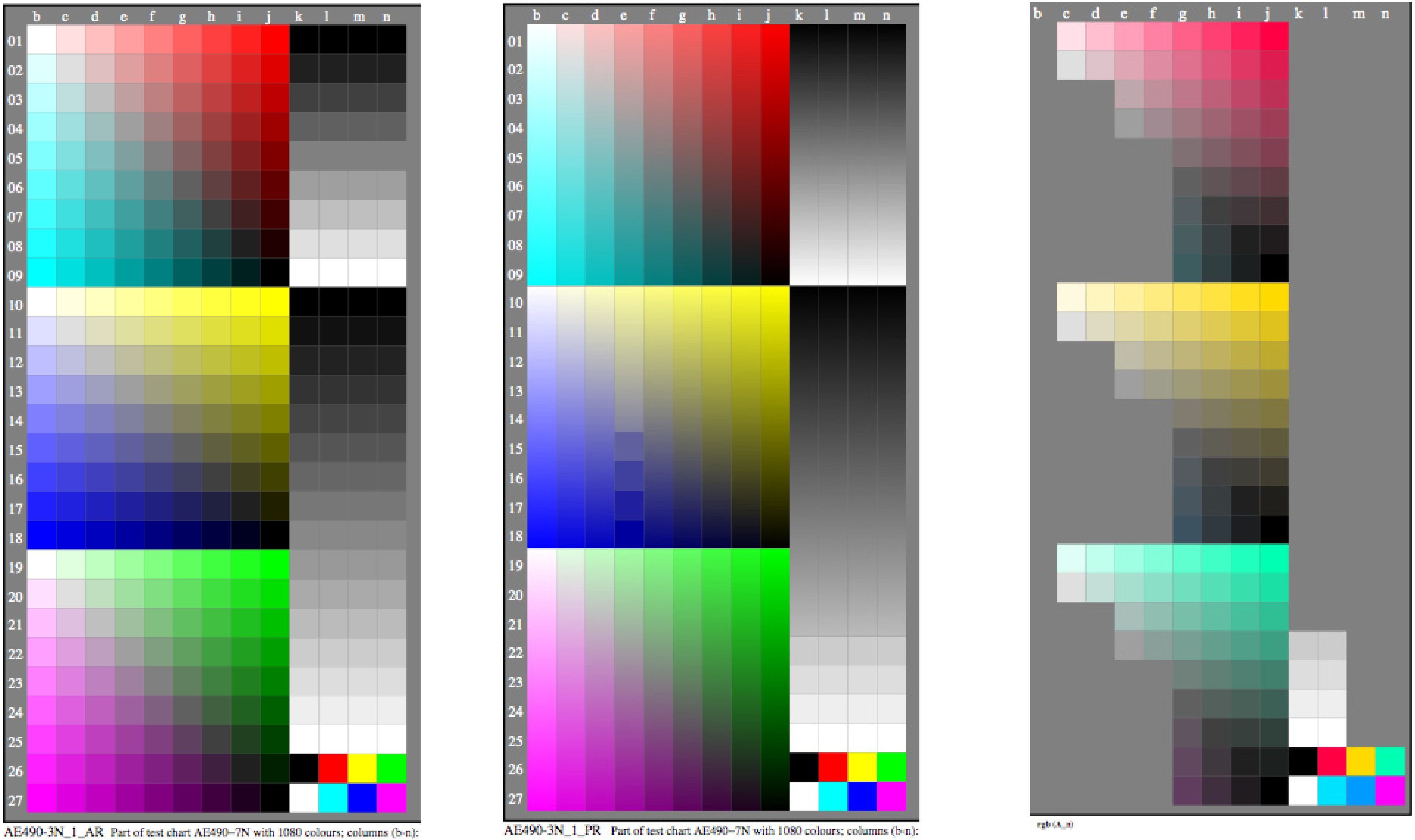


Figure 7: Display output of Figure 5 with 351 colours, defined by *rgb* colour data
The three Figures show outputs of the rows 1 to 27 and the columns *k* to *n* of Figure 5.

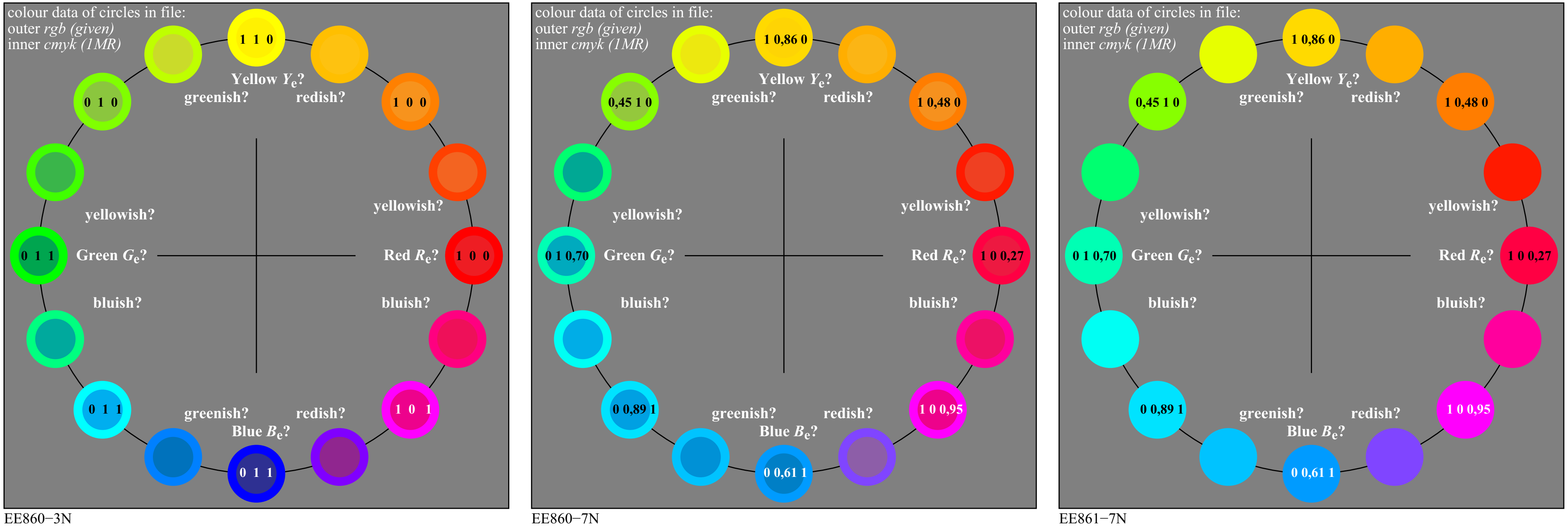


Figure 8: Output of a 16 step colour circle with *Adobe Reader* and *Adobe FrameMaker*

Figure 8 includes colour data *rgb* **and** *cmy0 (in the inner circle)* which are calculated by the 1-Minus-Relation, for example *c*=1-*r*. In the middle and right Figure the calculation of the *rgb* data produces the CIELAB hue angles h_{ab} = 26, 92, 152, and 272 on an S_{rgb} display. The output of *rgb* and *cmy0* data is with *Adobe Reader (left and in the middle)* different and with *Adobe FrameMaker (right)* equal. The right output is expected for the three images by colorimetry and by the *EPS PostScript* programming manual.

A *PostScript* printer of the company *OKI* with the option *Colour management OFF shows equal outputs.* However, the outputs *(left and in the middle)* are different by *Adobe Reader* and with the option *colour management ON* by the *OKI printer*. Users are confused and a standard is needed.

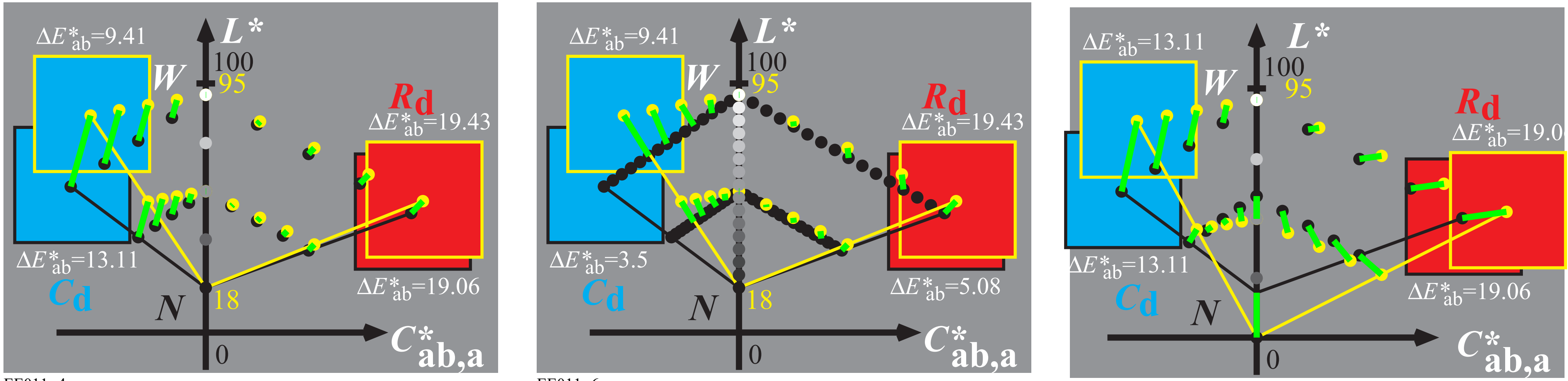


Figure 9: Affine transformation of colours in CIELAB hue planes

The colours in the hue planes of print and display have different values in the CIELAB chroma *C**ab. The shown affine transformations (*left and right*) are well defined. This is not only true, if the range *L**=18 to *L**=95 is equal *(left)* but also for different ranges of *L* (right)*.

The transformation in the middle has the goal to keep the CIELAB colour values in the print and on the display. However, then the print or the display cuts larger areas. There are many solutions with some smoothing, which are intended by ICC-colour profiles. Often the result is not sufficient.

Colour profiles with the affine transformation have been used for the **print of the colour atlas *RECS (Relative Elementary Colour System)* with more then 2000 colour samples**.

A software or hardware RIP *(Raster Image Processor)* allows the transformation of 16,7 million (256x256x256) *rgb* input values to *rgb'* output values. The unique transformation uses the input value as an index and uses the output value by a very fast way.

For the print of the *RECS* an *appropriate fixed* transformation from *rgb* to *cmyk* was used which includes already the first output of the 729 colours of the ISO test chart AE49. The fixed transformation *rgb* to *cmyk* remains for the linearized output of the final colour atlas *RECS*.

6. Ergonomic display output, Joint work between CIE and ISO

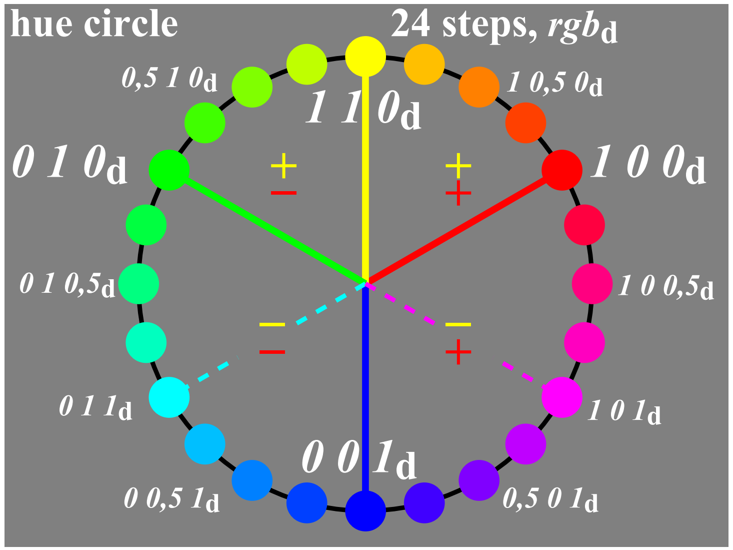
Conclusion 31/2007 ISO TC159/SC4/WG2

Ergonomics − Visual Display Requirements

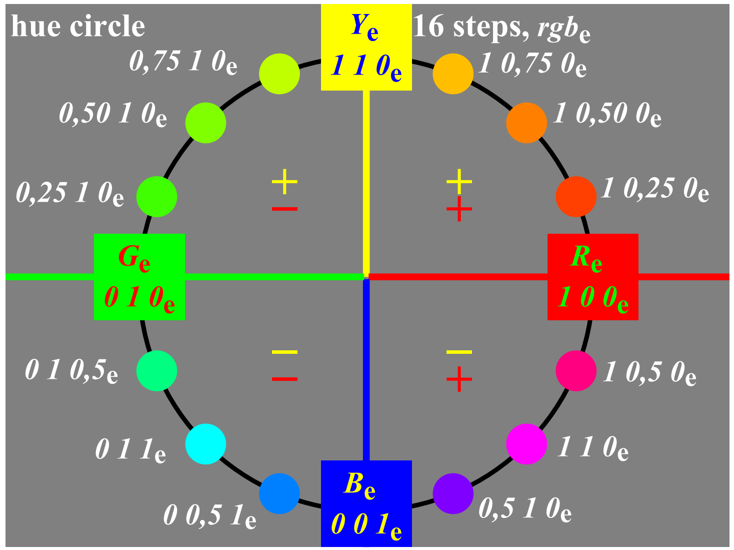
ISO TC159/SC4/WG2 realizes that the colour spaces CIELAB and CIELUV of ***CIE Division 1*** will soon become ISO/CIE standards. In applications we use these CIE colour spaces and *device−dependent* relative RGB colour spaces. For users of visual display systems a *device−independent* RGB colour space is useful. This produces via software the elementary hues Red, Green and Blue for the RGB data 100, 010 and 001 and equally spaced output in CIE colour spaces for equally spaced RGB input. We recommend that ***CIE Division 1*** study the colorimetric definition of such a space, which can be used in visual display applications.

Remark: We have realized that an example colour space of this type is published in CIE X030:2006, p. 139−144.
Note: For this table text compare the content on page 2 of the document CIE R1-47, see http://files.cie.co.at/526.pdf

EE850−1N



EE840−7N



EE840−8N

Figure 10: Ergonomic visual display requirements for production of elementary colours.
CIE R1-47 defines the CIELAB hue angles h_{ab}=26, 92, 162 und 272 for R_e, Y_e, G_e, and B_e.

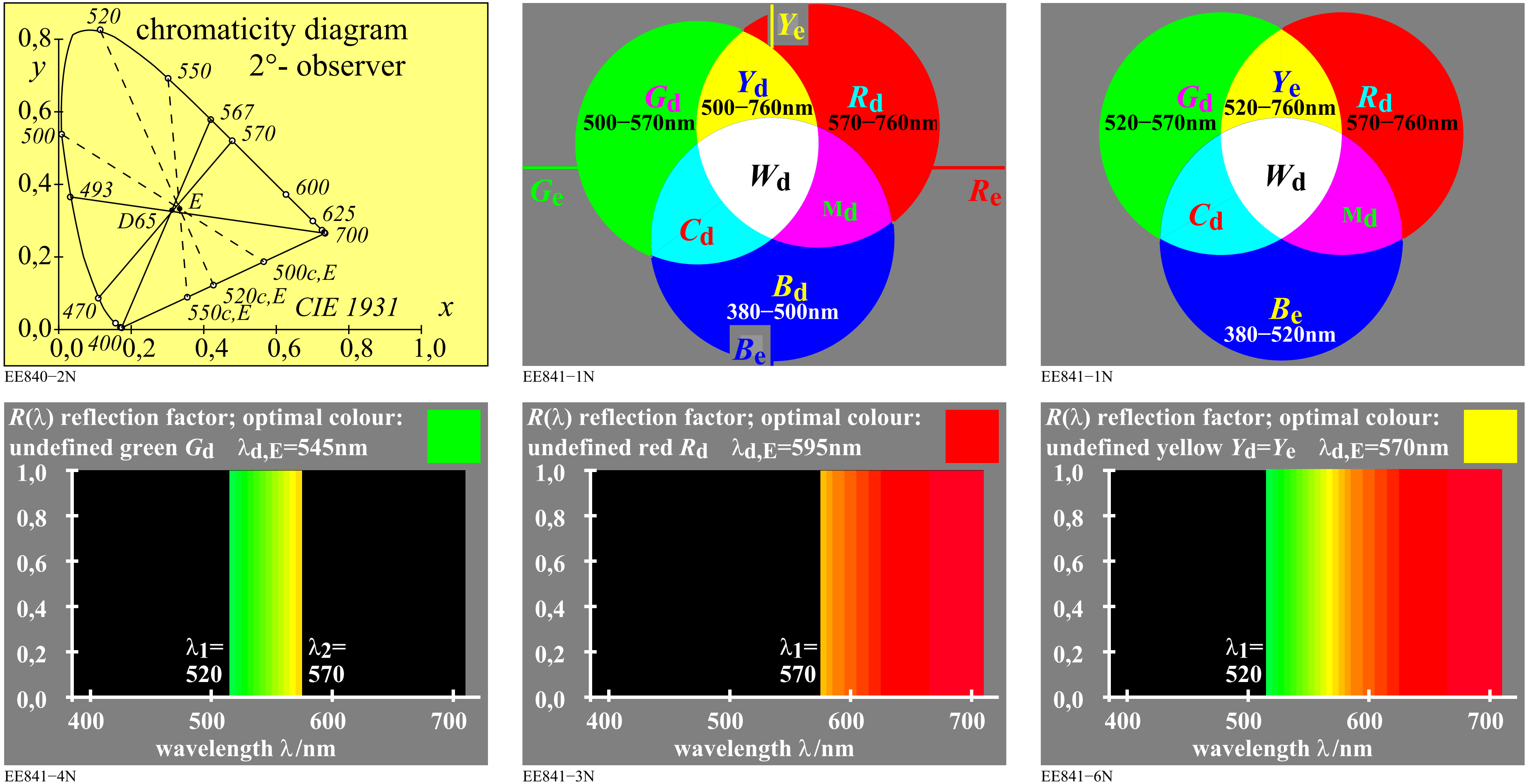
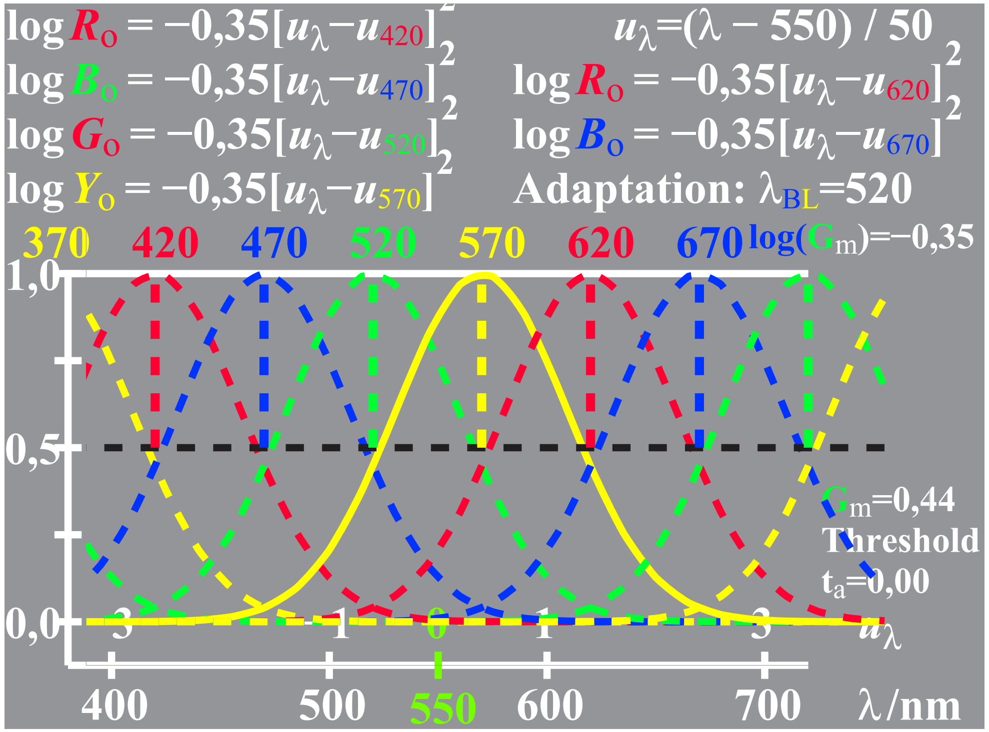


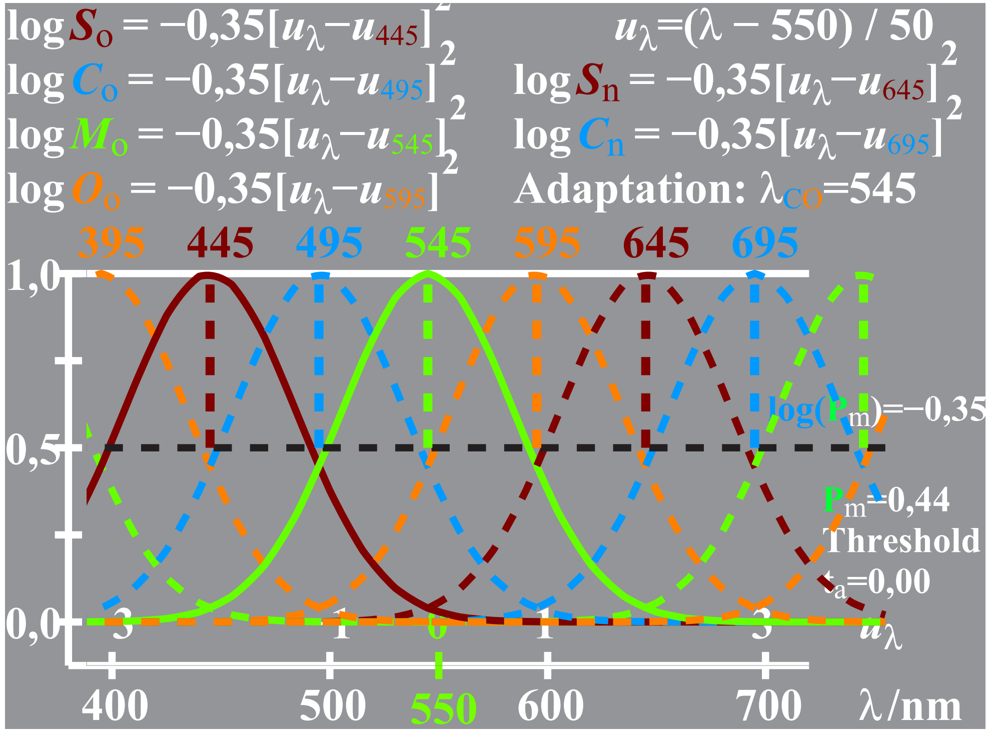
Figure 11: Mixture of the elementary colour *Ye* from two Optimal colours *G*d and *R*d

Figure 11 shows the mixture of 2 complementary optimal colours in the CIE chromaticity diagram. The spectral mixtures on the *left* and *right* side of lines, for example through the chromaticity of D65 mix to white. The elementary colour yellow *Y*e with the dominant wavelength 570nm is mixed by a spectral range from 520nm to 760nm. This range consists of the colours *G*d and *R*d. CIE R1-47 recommends the CIE colours no. 9 to 12 of CIE 13.3 for the h_{ab} definition.

7. Sensitivities of three *LMS* receptors and of many calculated other receptors



1EE870−8A



1EE871−8A

Figure 12: Model sensitivities *L*(570nm), M(545nm), and S(445nm) of equal shape.

The *LMS* model sensitivities are approximately equal to the *LMS* sensitivities of CIE170-2.

Figure 12 shows two classes of sensitivities of equal bandwidth (100nm). The first class has maxima by 420, 470, 520, and 570nm. The second class has maxima by 445, 495, 545, and 595nm. The formulae for the calculations are given in Figure 12. The colours are chosen by the elementary colours and their intermediate colours. The hue position corresponds to Figure 10.

Of special importance are the opponent colours, for example yellow and blue. The colour values are approximately anti symmetric similar to the 1-Minus-Relation (1MR), for example *C*=1-*R.*

All model sensitivities can be calculated by *logarithmic* or *linear sums* or *differences* of the *LMS*-model sensitivities. The result is a special colorimetry which is more simple to understand.

8. Special colorimetry of the *Ostwald* colours

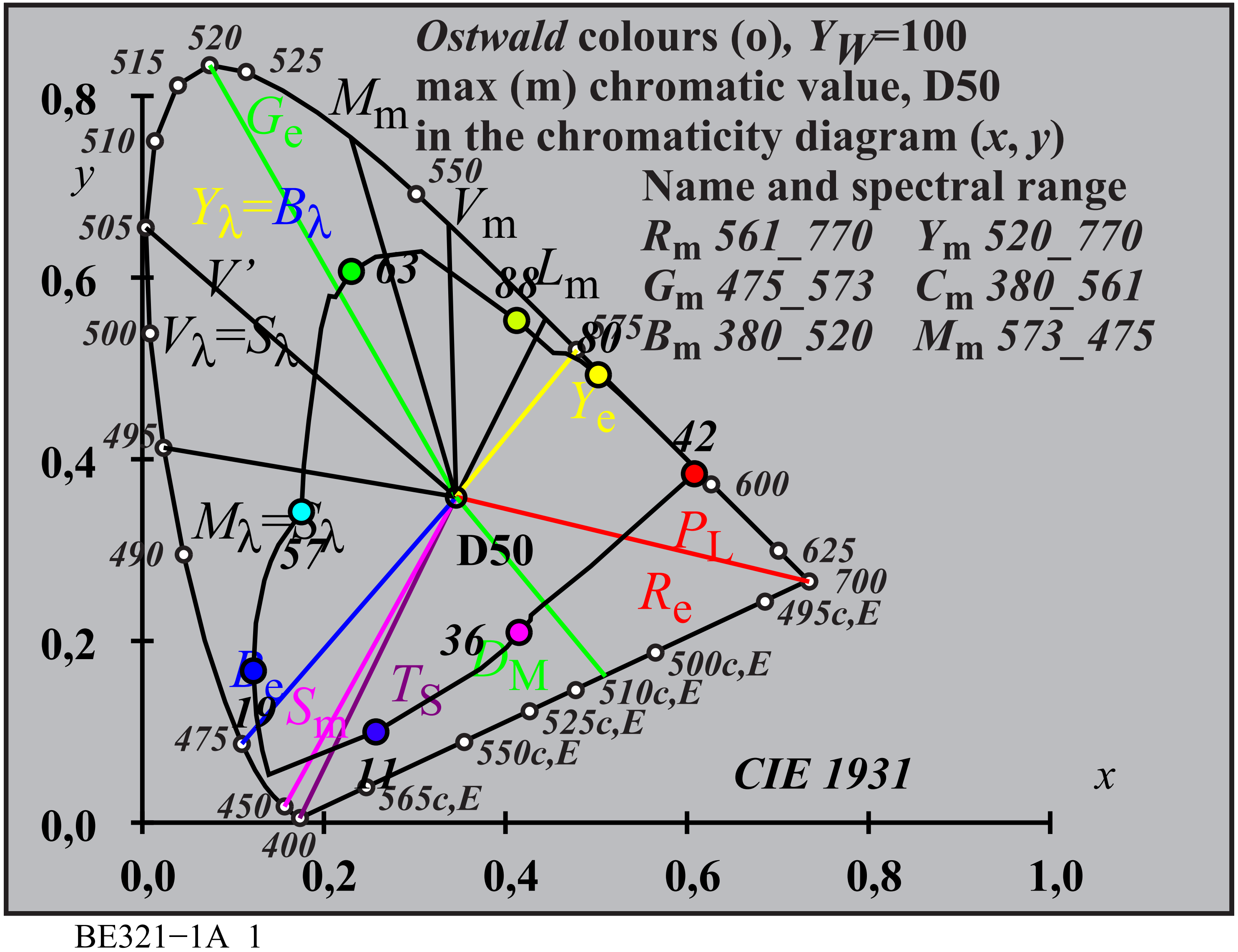
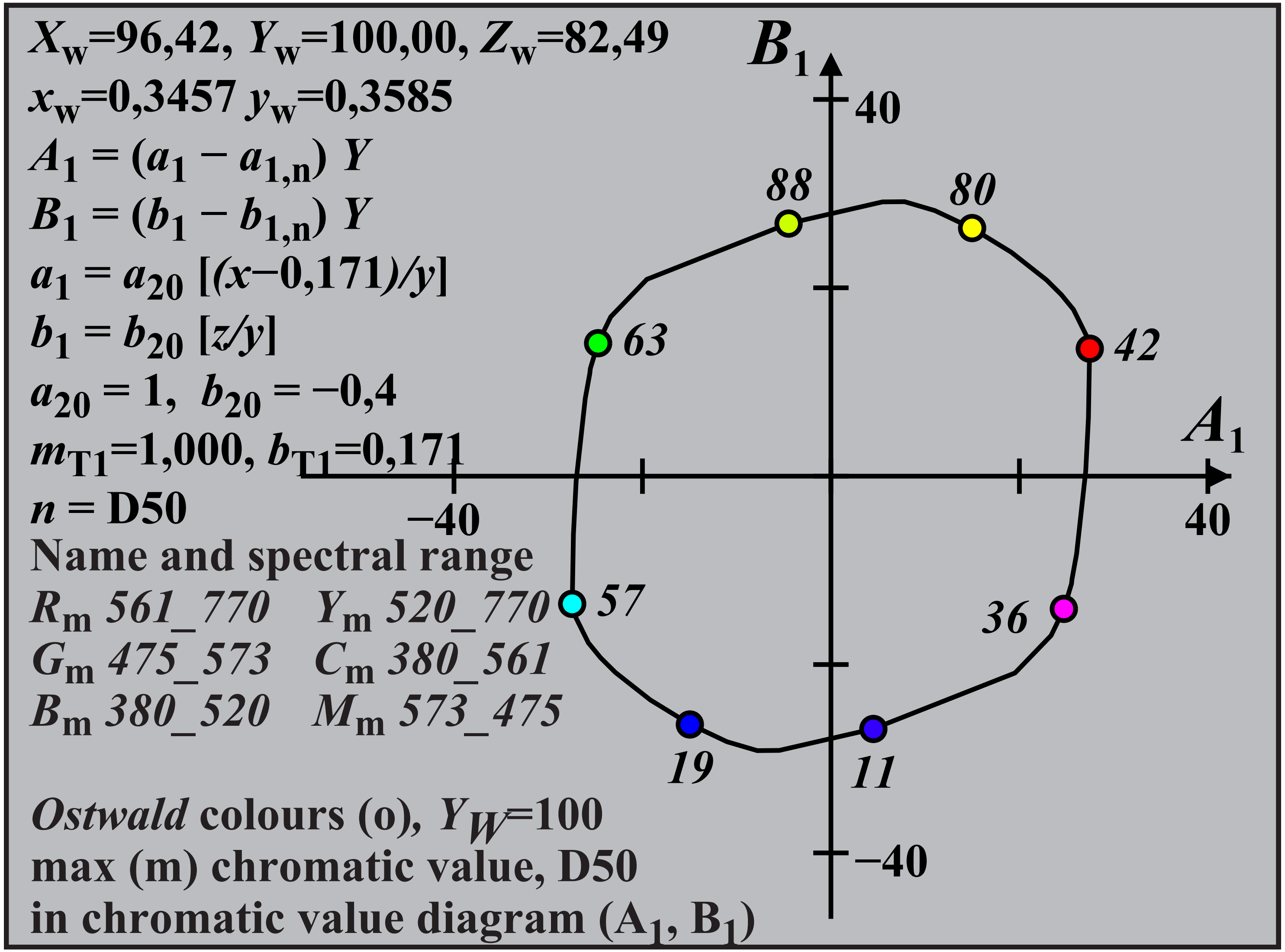


Figure 13: Chromaticity diagram with *Ostwald* optimal colours with (L,M,S)m, PL and TS
Figure 13 shows the *Ostwald* hue circle of optimal colours for D50. The maximal sensitivities (L, M, S)m, and the confusion lines PL und TS of colour defective observers P and T are shown.



BE321−3A 1

Figure 14: Colour values of *Ostwald optimal colours* (colour halve) as hue circle for D50

Figure 14 shows an *Ostwald* hue circle of optimal colours with the defined six wavelength ranges and the tristimulus value *Y* as parameter. The colour values are anti symmetric.

The shape of approximately a circle for colours with $11 <= Y <= 88$ leads to a special colorimetry.

9. Standardization and revision on a *ergonomic* and colorimetric fundament.

Input	Output	Input and output media and applications: Input	Output	Application	Technical Report (TR) or Standard	Method & Test: Linearization
–	–	–	–	**Basis**	**ISO/IEC TR 24705**[3)] **former DIS 19839-1**[3)]	**DIN 33866-1** **DIN 33872-1**
analog[2)]	**analog**	ISO/IEC-file series equally spaced in *rgb** ISO/IEC-test chart (hardcopy) series equally spaced in *LCh**	Hardcopy	**Copier**	**ISO/IEC 15775** **under revision**	**DIN 33866-2** [2)] **JIS X 6933**[1) 2)]
analog[2)]	**digital**	ISO/IEC-test chart (hardcopy) series equally spaced in *Lch**	File	**Scanner**	**ISO/IEC TR 24705**[3)] **former DIS 19839-3**[3)]	**DIN 33866-4**
digital[1)]	**analog**	ISO/IEC-test chart (File) series equally spaced in *rgb**	Hardcopy	**Printer**	**ISO/IEC TR 24705**[3)] **former DIS 19839-2**[3)]	**DIN 33866-3** **DIN 33872-2,4**
			Softcopy	**Display**	**ISO/IEC TR 24705**[3)] **former DIS 19839-4**[3)] **ISO 9241-306:2018**[1)]	**DIN 33866-5** **DIN 33872-2,4**

1) Digital ISO-test files for free download from: http://standards.iso.org/iso/9241/306/ed-2/index.html
2) Analog ISO-test charts are available from 3 sources: DIN 33866-2, JIS X 6933, *Richter, 2012,* offset print (3600dpi), siehe *Colour and Colour Vision,* compare as file http://standards.iso.org/iso/9241/306/ed-2/ES15.PDF
3) Free download of content of ISO documents for example for new standard projects, see many URLs in: http://farbe.li.tu-berlin.de/EE68/EE681-3N.PDF

ISO/IEC-input linearization method

Input	Output	Application	Technical Report (TR) or Standard
Original scene + CIE colours	ISO/IEC Image File	Reference Image File	**ISO/IEC 15775** **ISO/IEC TR 24705**

ISO/IEC-output linearization method, OUTLIN16_01.PDF

Input	Output media	Application	Technical Report (TR) or Standard
ISO/IEC File	Hardcopy	Printer	**ISO/IEC TR 19797**[3)]
ISO/IEC File	Softcopy	Display	**ISO 9241-306:2018** 8 viewing conditions
ISO/IEC File	Softcopy Hardcopy Hardcopy	Display Offset Printer	**CIE R8-09:2015** (CIE internal) + http://farbe.li.tu-berlin.de/OUTLIN16_01.PDF

EE680−7N

Figure 15: Relationship of standard documents of CIE, ISO, and DIN in the IT area.

The revision of the standards in Figure 15 needs a lot of efforts. However, this effort is required.

10. Results and future work

Some new developments of colorimetry have been shown which can be applied.
This are:

1. the elementary optimal colours and the elementary colours of CIE 13.3 and CIE R1-47.
2. the *Ostwald* optimal colours for the *device independent rgb** colour coding of CIE R1-57.
3. the relationship of the *LMS*-receptor sensitivities with elementary optimal colours.

These relationships are a new fundament of:

1. the *device independent* elementary hue output according to ISO 9241-306:2018,
2. the completely *device independent rgb** colour coding of CIE R1-57 for all surface colours.

The *device independent* elementary hue output and the *affine* reproduction has been already used in 2009 for the print of the colour atlas *RECS* with more then 2000 colour samples. Because of the large calculation power software and hardware *RIPs* can now contribute to the harmonization of the colour output and input. A standardization of the interface of *RIPs* or filters with

16,7 million *rgb* colour input values as index
16,7 million *rgb'* or *cmyk'* output values,

which can be filled and used by users, is especially important. Eight of these profiles are required for the application of ISO 9241-306.

A revision of the standards in Figure 15 needs special efforts. However the *ergonomic colorimetric* and *device independent* hue output is a required step and is supported by the above special colorimetry
The last versions of ISO/IEC DIS 19839-1 to -4 may be used as starting point for a revision of the standards. they are freely available, because until 2006 all ISO/IEC documents have been public. The ergonomic output seem to conflict often with the colour output interest of companies.

11. References

Adobe PostScript (PS) and Portable Document Format (PDF) Reference Manuals, see http://adobe.com

ISO 9241-306:2008, ISO/DIS 9241-306:2017, ISO EN DIN 9241-306:218: Ergonomics of human-system interaction - Part 306: Field assessment methods for electronic visual displays *(the first two documents use EPS vector graphic and are of high quality. The last one includes only pixel graphic. The images are of low quality)*

IEC 61966-2-1, Multimedia systems and equipment — Colour measurement and management — Part 2-1: Colour management; Default RGB colour space; sRGB

ISO/IEC 15775:1999 and 2005 *(under revision in 2019)*, Information technology — Office machines — Method of specifying image reproduction of colour copying machines by analog test charts — Realization and application

ISO/IEC TR 24705:2005 *(withdrawn in 2019)*, Information technology — Office machines — Machines for colour image reproduction — Method of specifying image reproduction of colour devices by digital and analog test charts. *For test charts for specifying image reproduction with different PS parameters, different resolutions, and an ISO/IEC-image, see* http://farbe.li.tu-berlin.de/A/24705TE.html

DIN 33872-1 to -6:2010, Information technology — Office machines — Method for specifying relative colour reproduction properties with YES/NO criteria. *For test charts for specifying relative image reproduction, see* http://farbe.li.tu-berlin.de/A/33872E.html

For a filled out form for output questions see for example (look for many others nearby) http://farbe.li.tu-berlin.de/LE95.

ISO 11664-4:2008(E)/CIE S 014-4/E:2007: Joint ISO/CIE Standard: Colorimetry — Part 4: CIE 1976 *L*a*b** Colour Space

ISO/CIE 11664-6:2014(E): Joint ISO/CIE Standard: Colorimetry — Part 6: CIEDE2000 Colour Difference Formula

Richter, Klaus (2016a), Colour and Colour Vision and Elementary Colour in Colour Information

Technology, 85 pages (A5), *see* http://farbe.li.tu-berlin.de/color. *This paper includes printed achromatic and chromatic test charts according to ISO/IEC 15775, ISO/IEC TR 24705, and ISO/DIS 9241-306:2017, Annex D. These prints may be used as reference outputs. In addition this paper is available in 6 languages (85 pages (A5)) in PDF format for mobile reading.*

Richter, Klaus (2014), Trends for CIE-ISO-colour standards for input and output of all colour devices with relative CIELAB coordinates rgb* (15 pages, 700 KB), see
http://farbe.li.tu-berlin.de/CIE_TC42_DFWG_14E.PDF

Richter, Klaus (2009), Colorimetric supplement for DIN 33872-1 to 6 (available in German and English), see the URL (41 pages, 1,4 MByte)

http://farbe.li.tu-berlin.de/A/D33872-AE.PDF

The following two **public** papers are given in the **standard reference format MLA** which gives two options to find these papers:

Thorstein Seim, Reportership Report CIE R1-47, Hue angles of elementary colours, 2009, see (35 pages),

[http://files.cie.co.at/526.pdf]._Internet Archive_.[http://web.archive.org/web/20160304130704/http://files.cie.co.at/526.pdf].

Thorstein Seim, Reportership Report CIE R1-57, Border between Blackish and Luminous Colours, 2013, see (23 pages),

[http://files.cie.co.at/716_CIE%20R1-57%20Report%20Jul-13%20v.2.pdf

Klaus Richter (2016), Output linearization method *OLM16* for displays, offset, and printers, see (60 pages, 1,3 MB))

http://farbe.li.tu-berlin.de/OUTLIN16_01.PDF

Remark: There is a closed similar Reportership Report CIE R8-09:2015 which is freely available only for members of CIE Division 8 via the CIE CollTool area with a member password.

Author: *Klaus Richter*, TU Berlin (TUB)

internet: http://farbe.li.tu-berlin.de or http://130.149.60.45/~farbmetrik

email: klaus.richter@mac.com