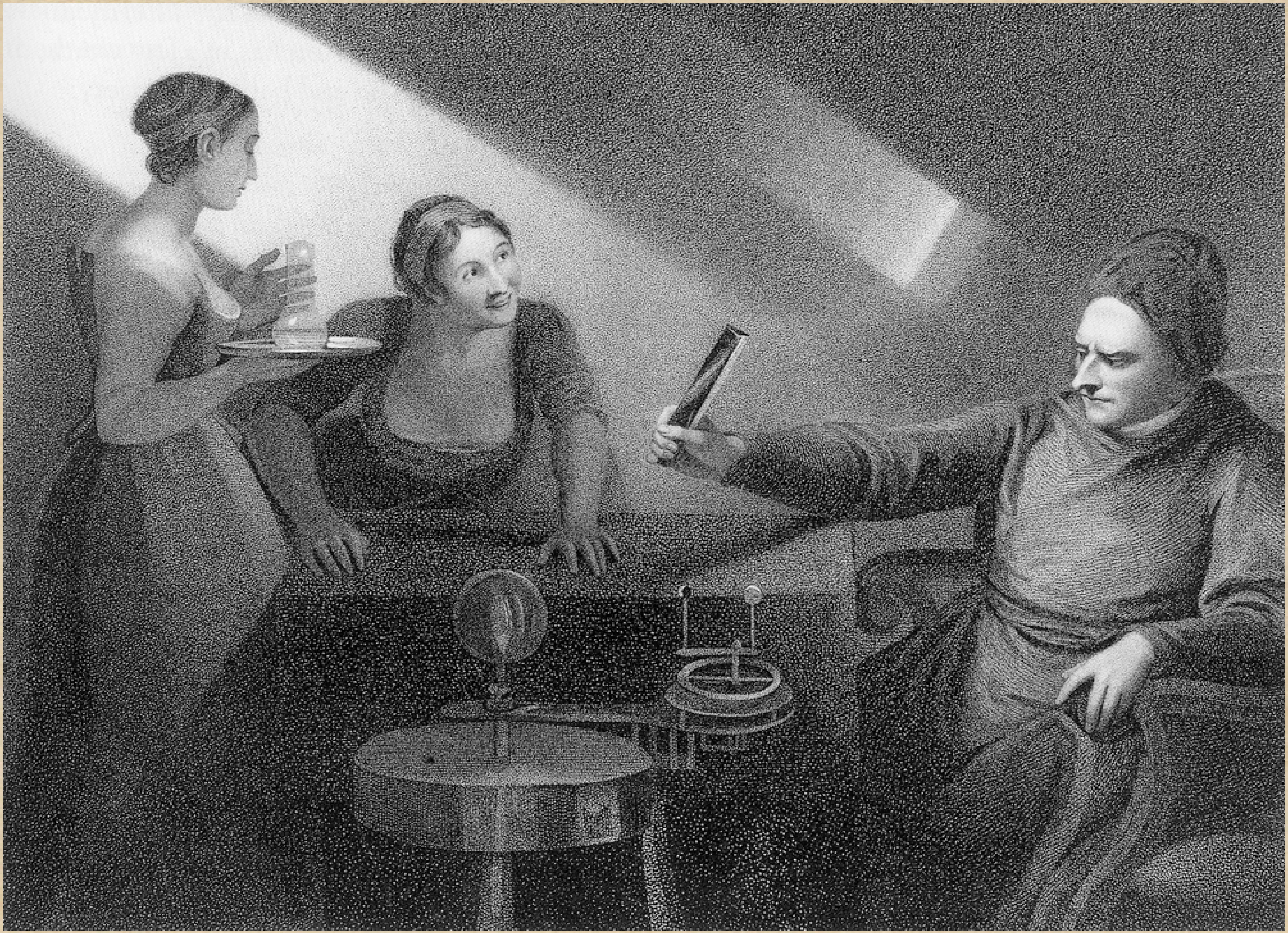
Ostwald and the Theory of Colors

Jan J. Koenderink
Physics & Astronomy, Universiteit Utrecht

Ostwald's Basic Contributions to Colorimetry are:

- the spectrum & the color circle (semichromes)
- the mensuration of the color circle
- the structure of the object color solid
- the colorimetric color atlas
- color & spectral signature
- *(I will not discuss color harmony today)*

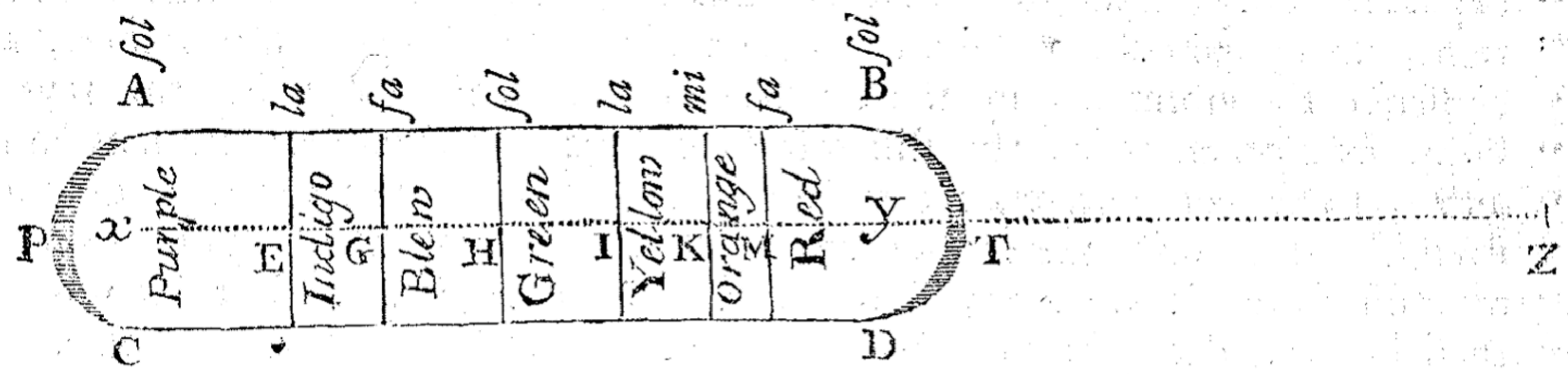
The Spectrum
&
the Color Circle



Newton demonstrates the spectrum (George Romney)

675.] ROYAL SOCIETY OF LONDON. 26

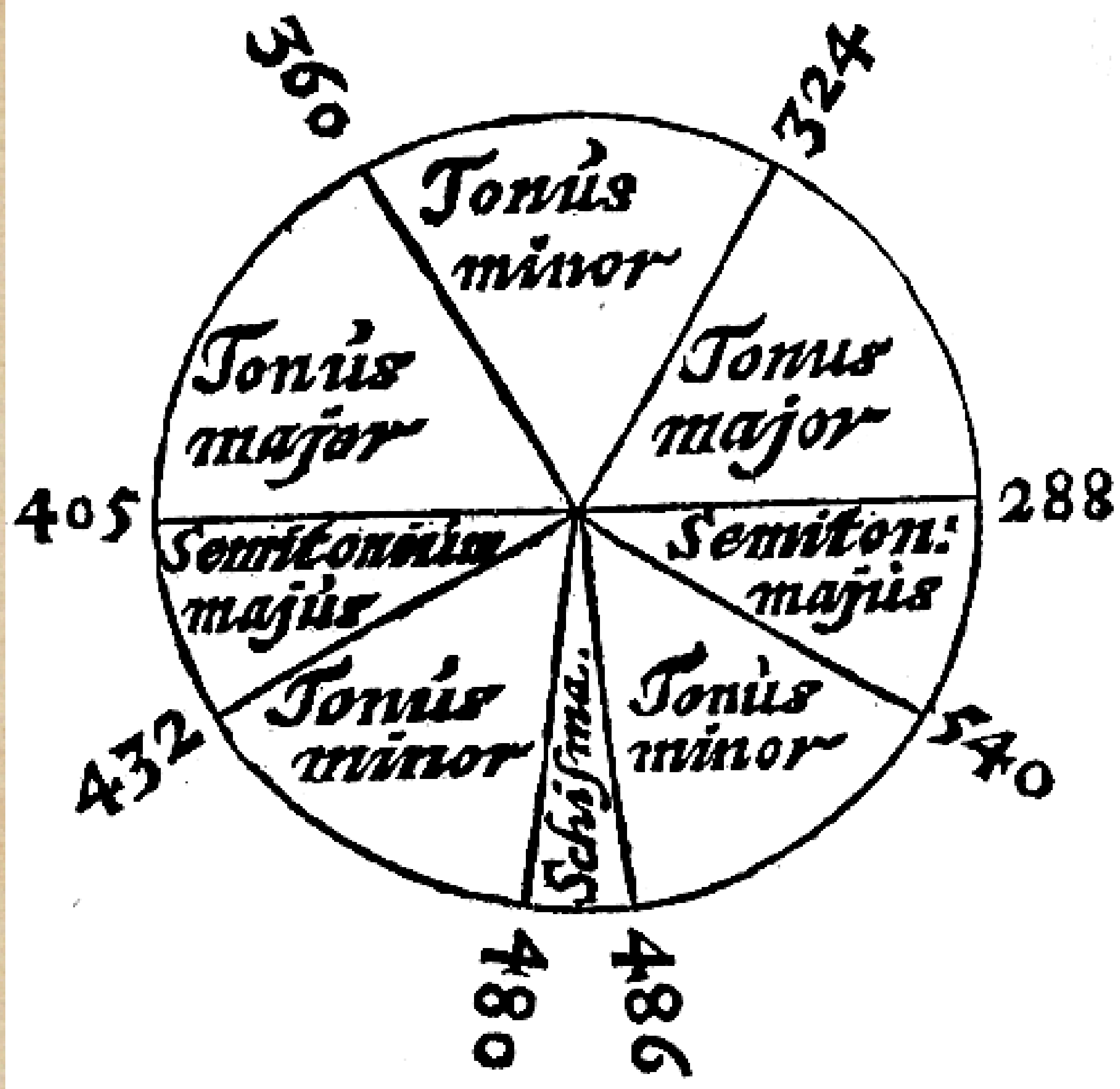
Y the centres of those ſemicircles, X Z the length of a muſical ſtring double to

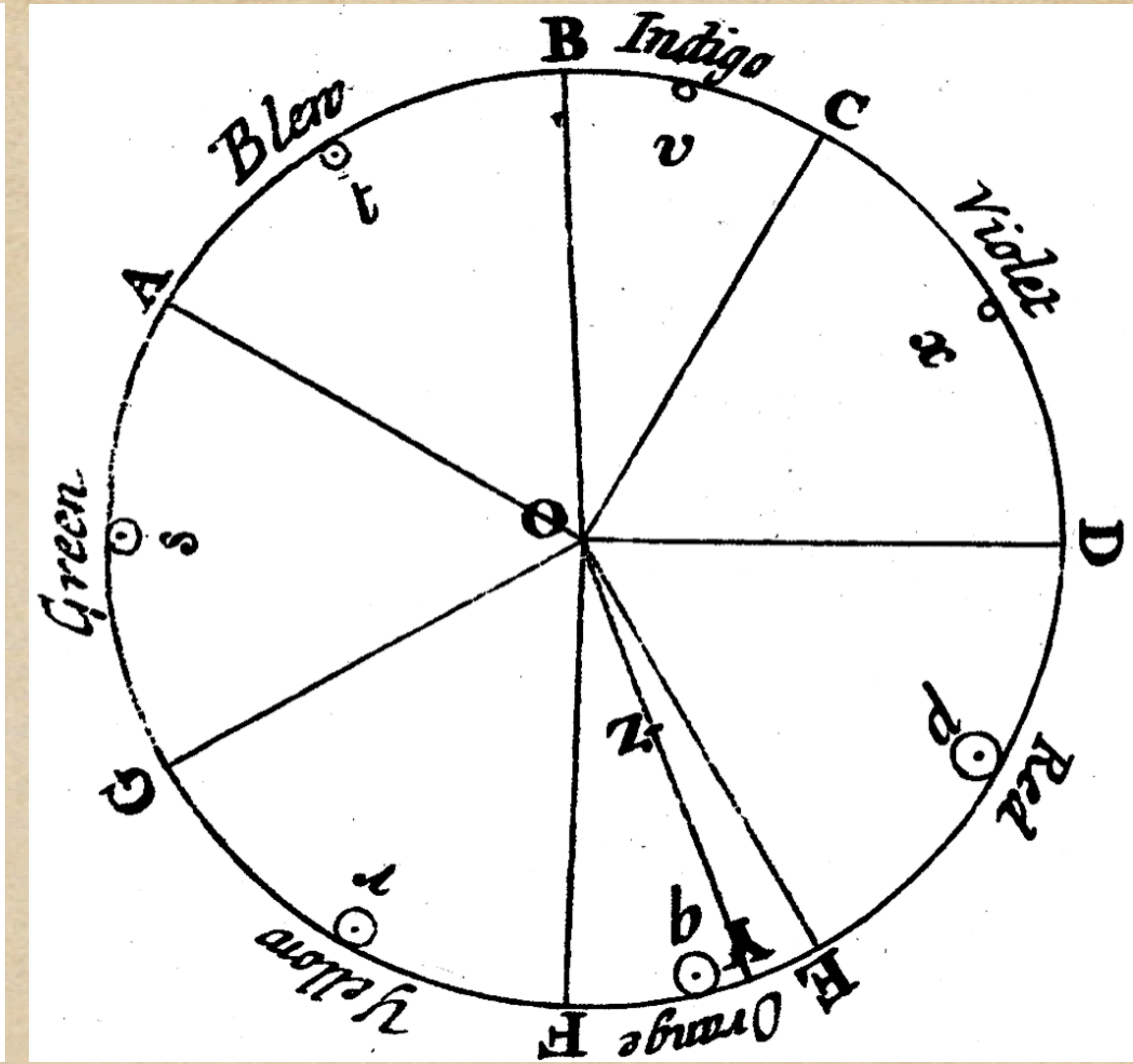


X Y, and divided between X and Y, ſo as to ſound the tones expreſſed at the ſide (that is X H the half, X G and G I the third part, Y K the fifth part, Y M the eighth part, and G E the ninth part of X Y) and

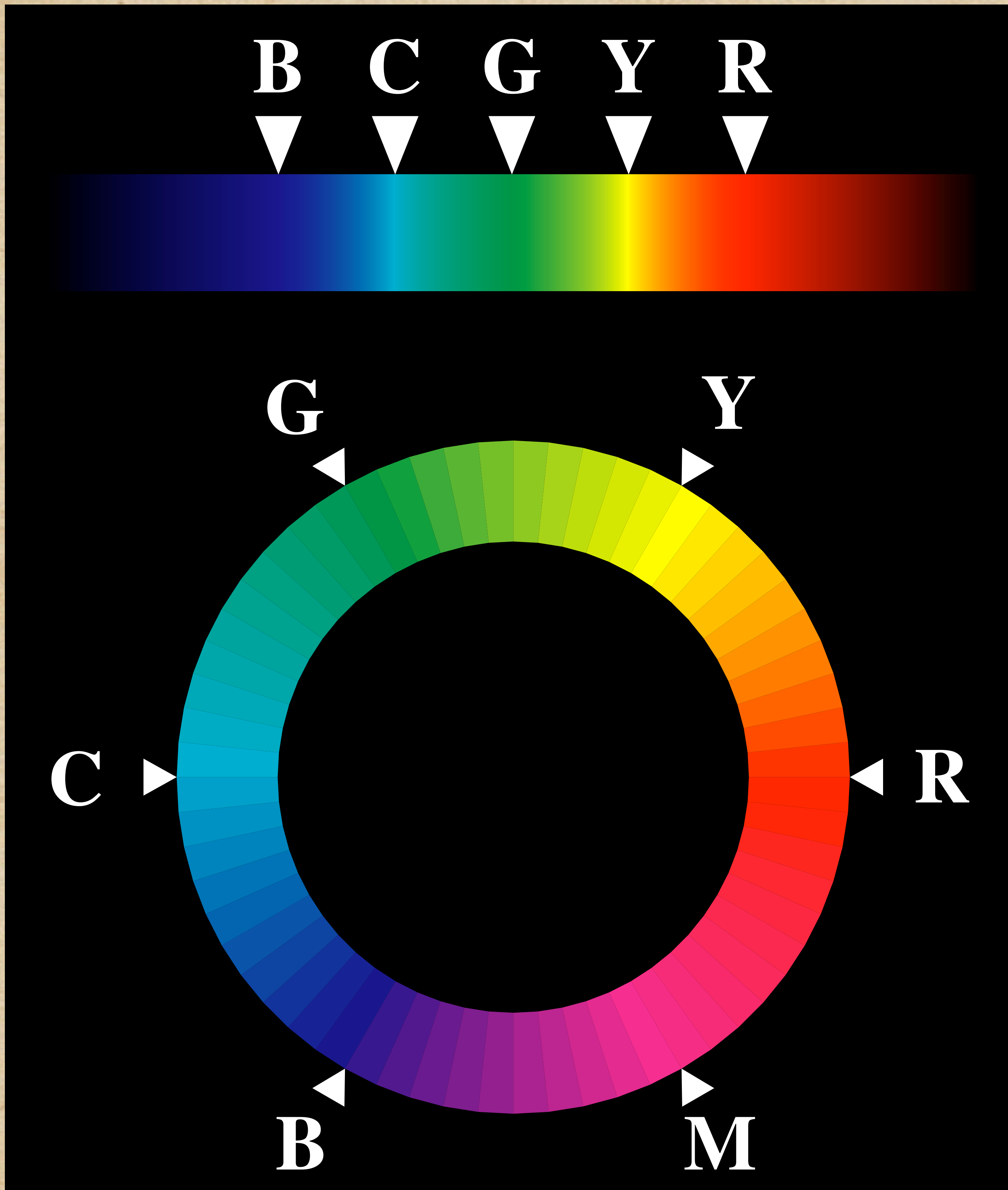
Newton's spectrum had a resolution of only about 50-100nm (but the colors were almost perfect!).

Newton saw 7(!) colors and fitted a musical scale to them.



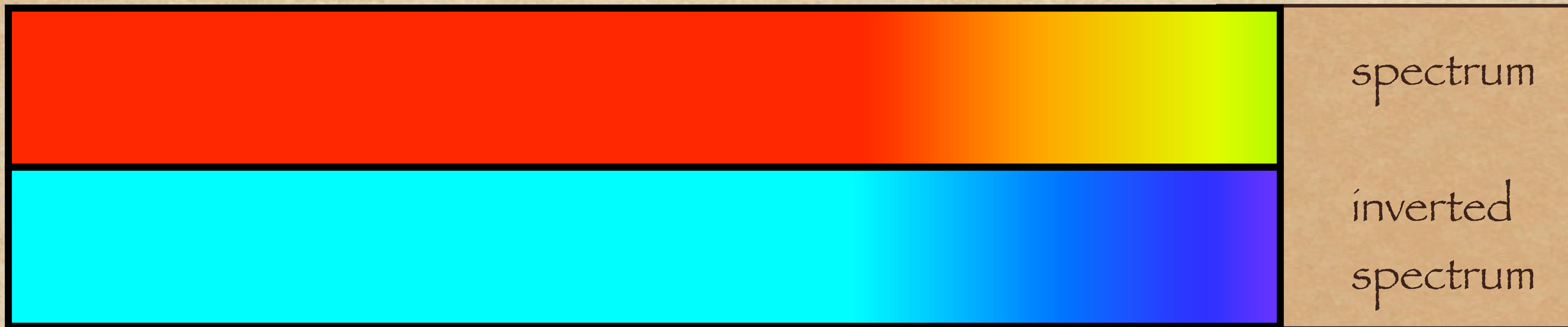


Newton drew up a color circle (right), he probably emulated Descartes' representation of the musical octave (left). He somehow managed to let the spectrum "bite its own tail", confusing the scientific world for over a century (till Maxwell's & Helmholtz's experiments).



Newton's spectrum is "not complete":
Only the painter's "color circle" contains all hues.

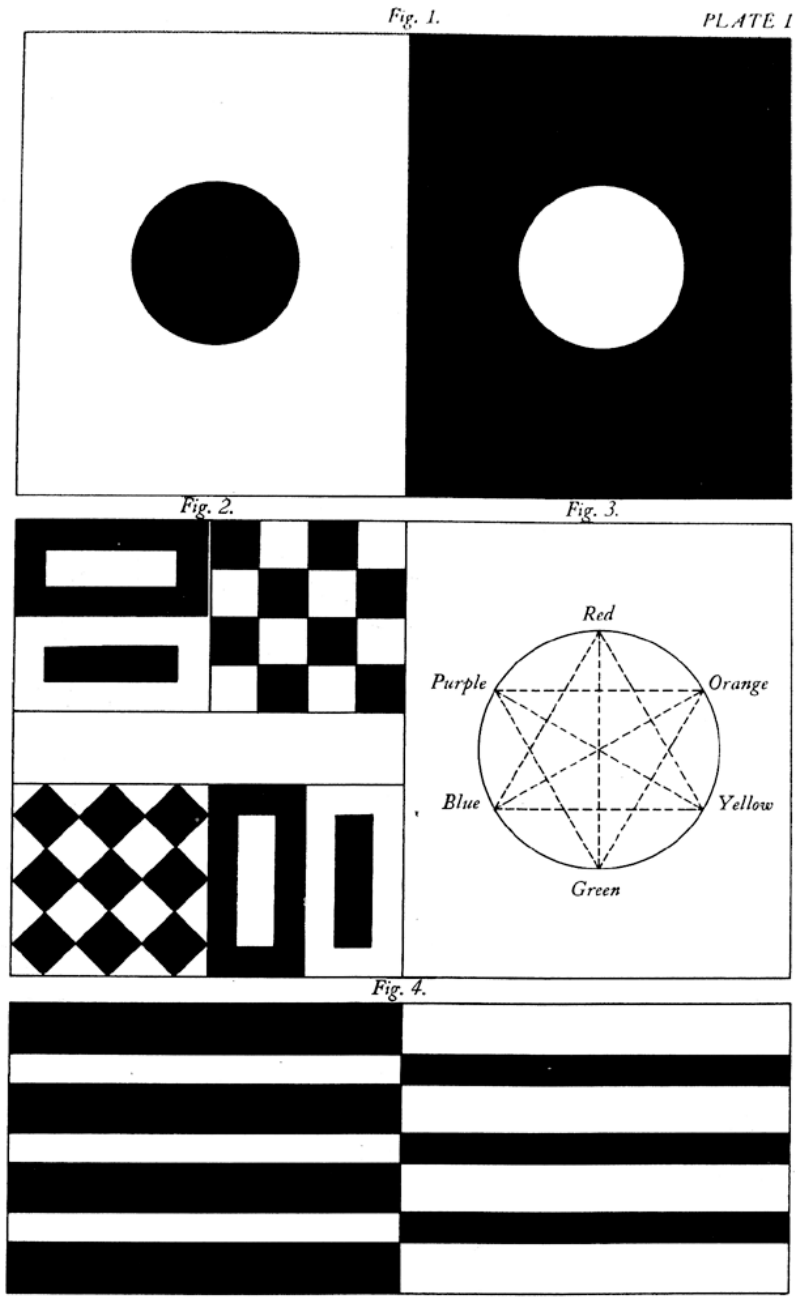
It remained for Ostwald to clear up the relation between the spectrum and the color circle.

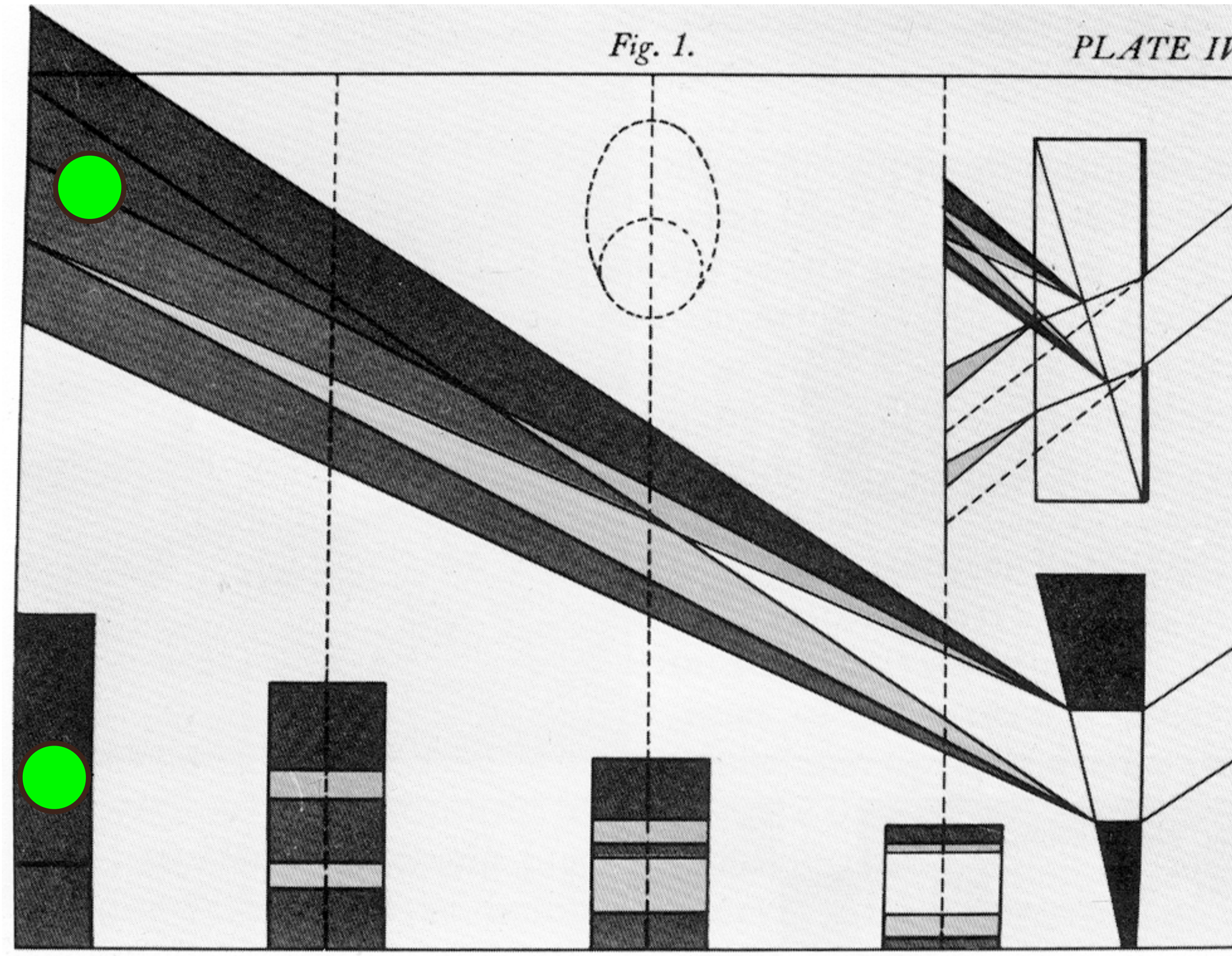


Newton thought he "proved" white light to be a "confused mixture of homogeneous lights".

Goethe (Farbenlehre) showed that complementary apertures yield complementary images (Babinet's Principle) and produced the "inverted spectrum".

Neither the spectrum, nor the inverted spectrum are complete. Goethe had trouble with green, Newton with purple.

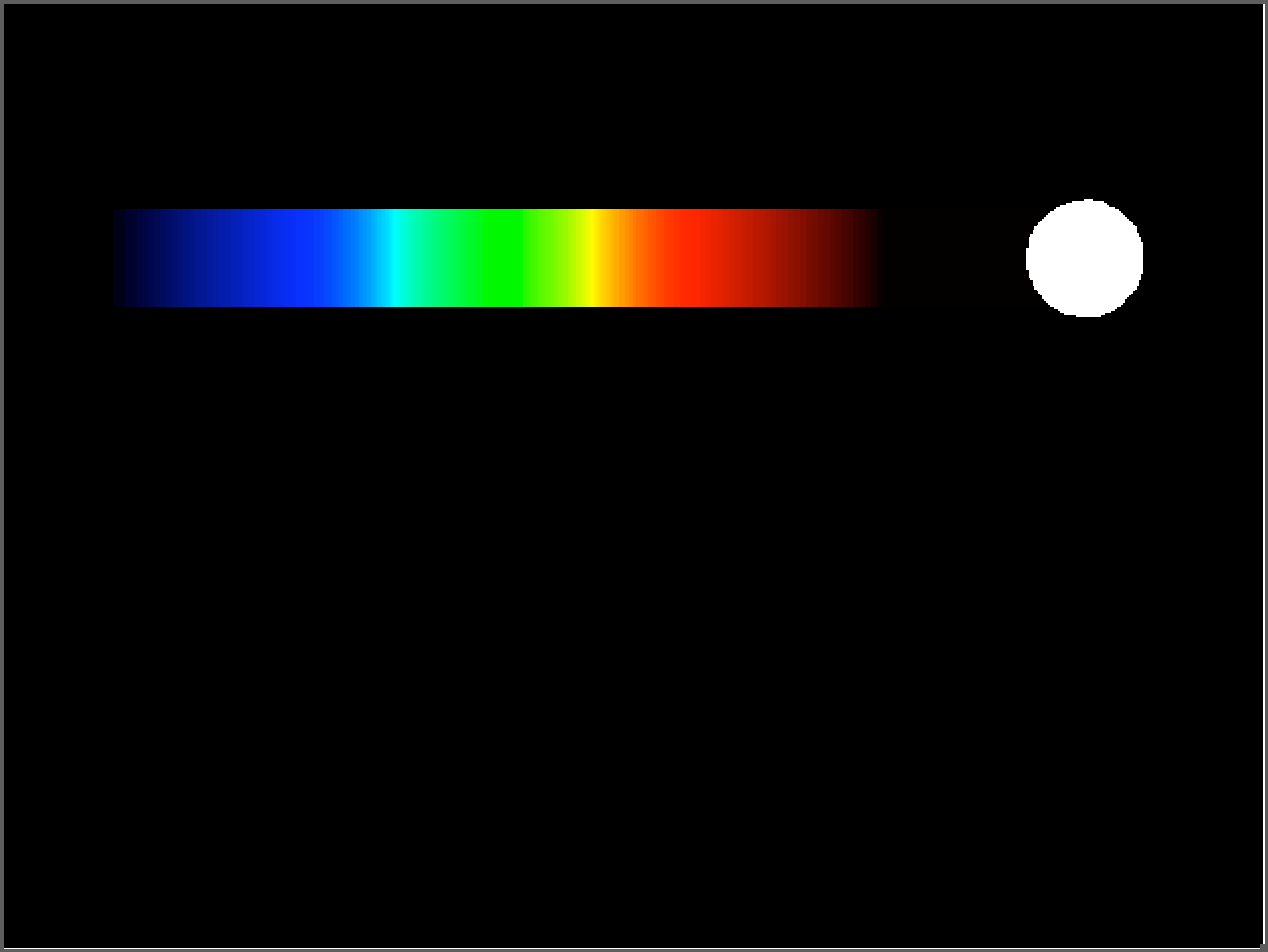




Goethe experimented with

He came to consider colors as mixtures of edge colors ("Kantenfarben"). This let to Schopenhauer's notion of colors as

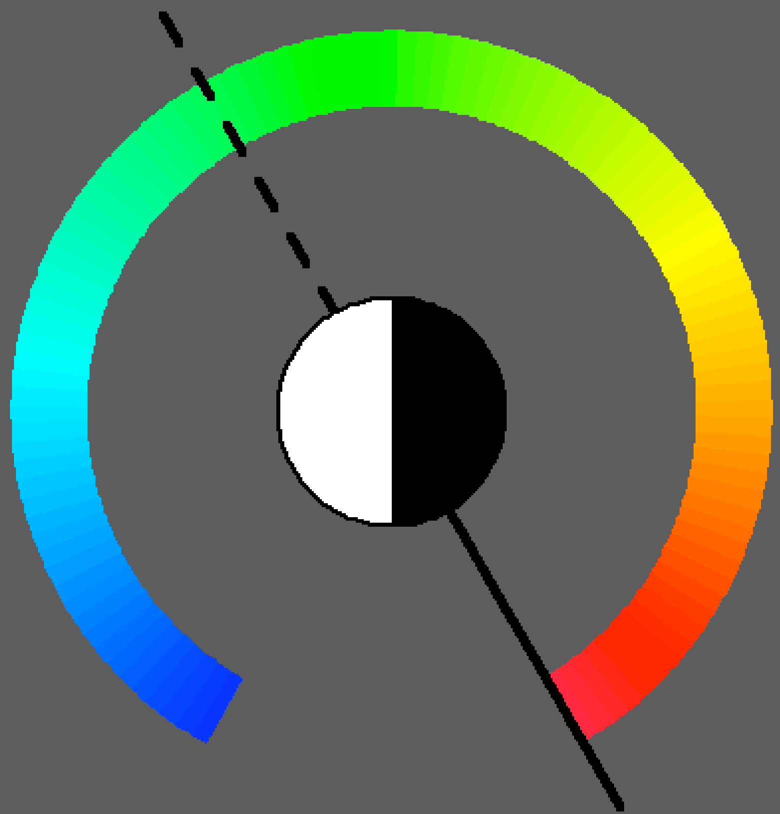
Goethe’s “edge colors” are obtained as the cumulated spectra (starting at either spectrum limit) of the spectrum of the illuminant (“white light”, “daylight”). You see these colors when you look at a light/dark edge through a prism.

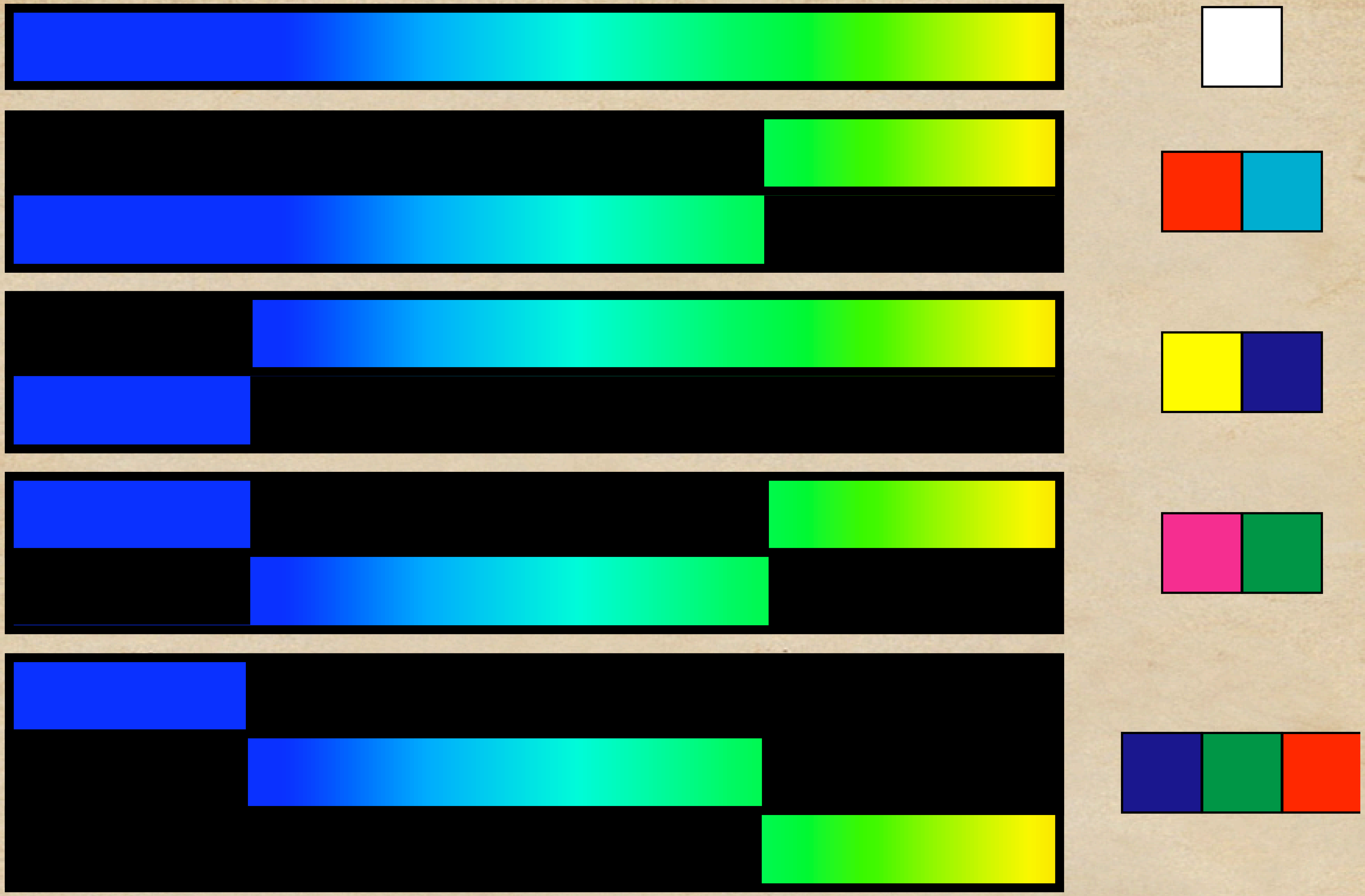


The Goethe edge colors as "parts of daylight" (cumulated spectra from either spectrum limit).

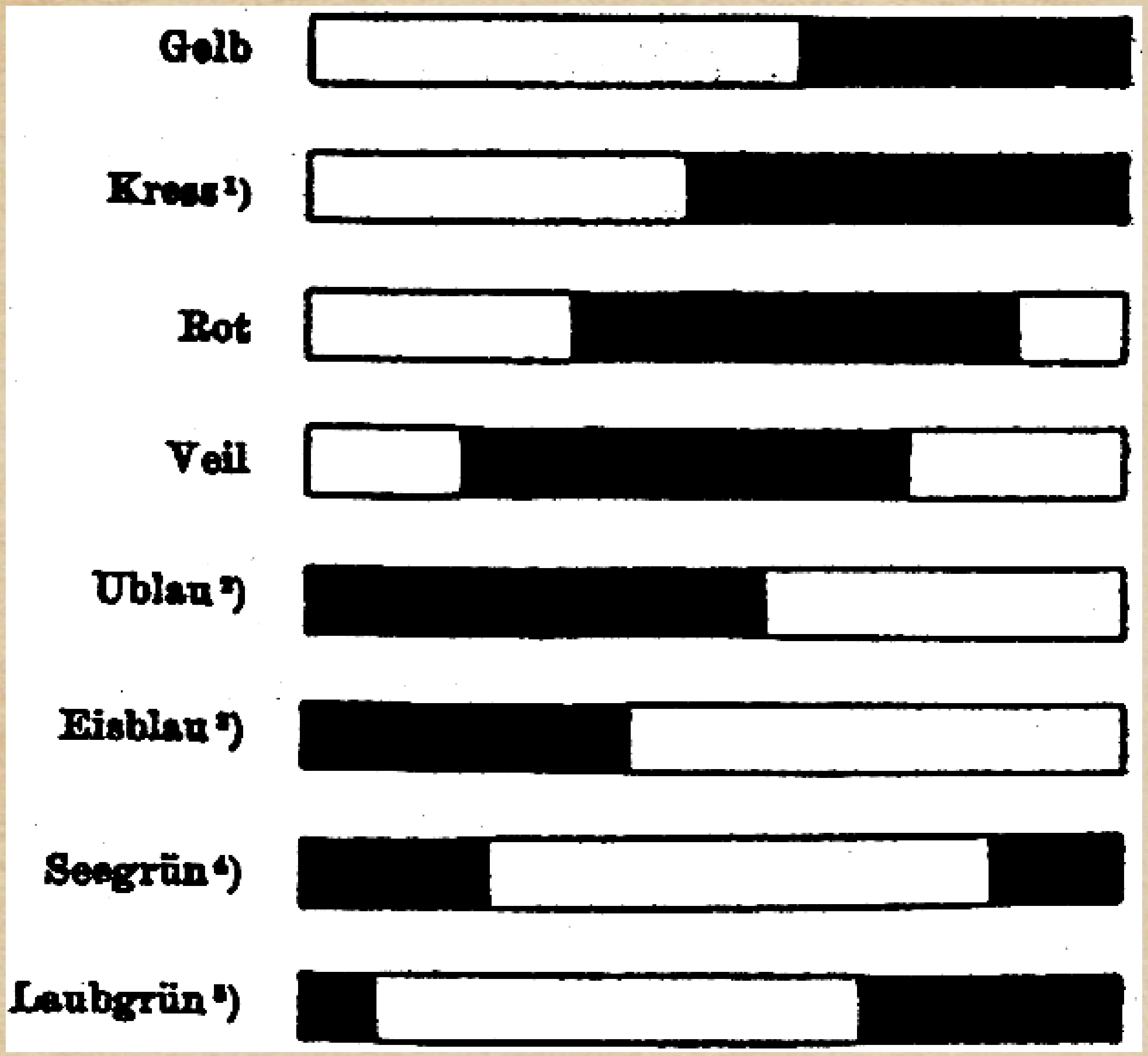
Schopenhauer (*Über das Sehn und die Farben*) noticed that there exist exactly two **best** bipartitions of daylight.

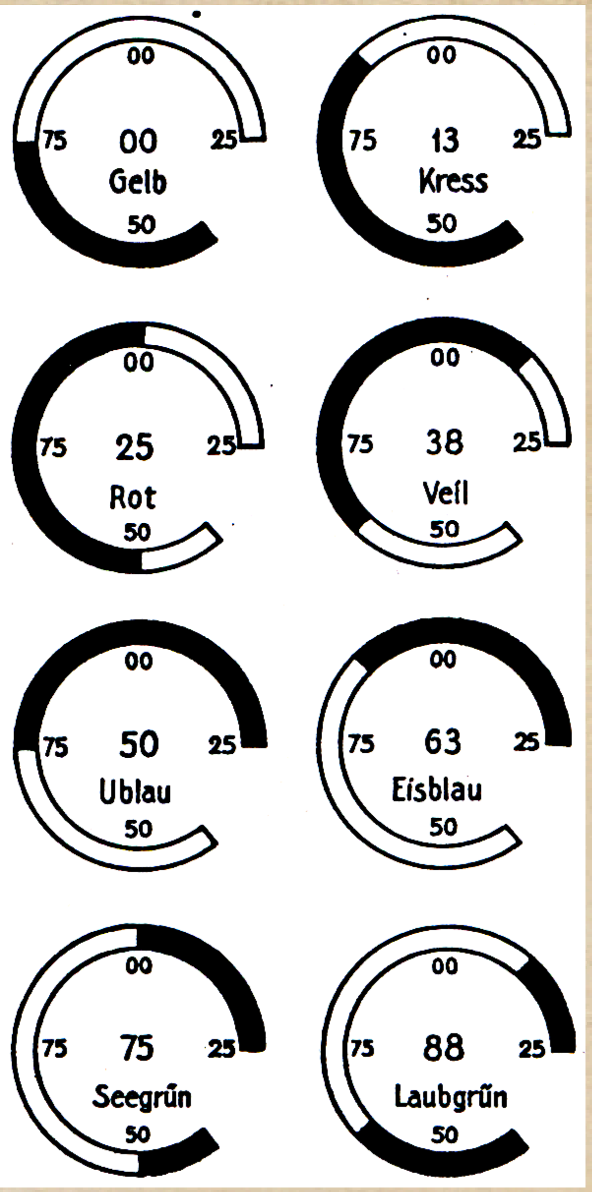
The cut locus is at the "antipodes" of the spectrum limits.



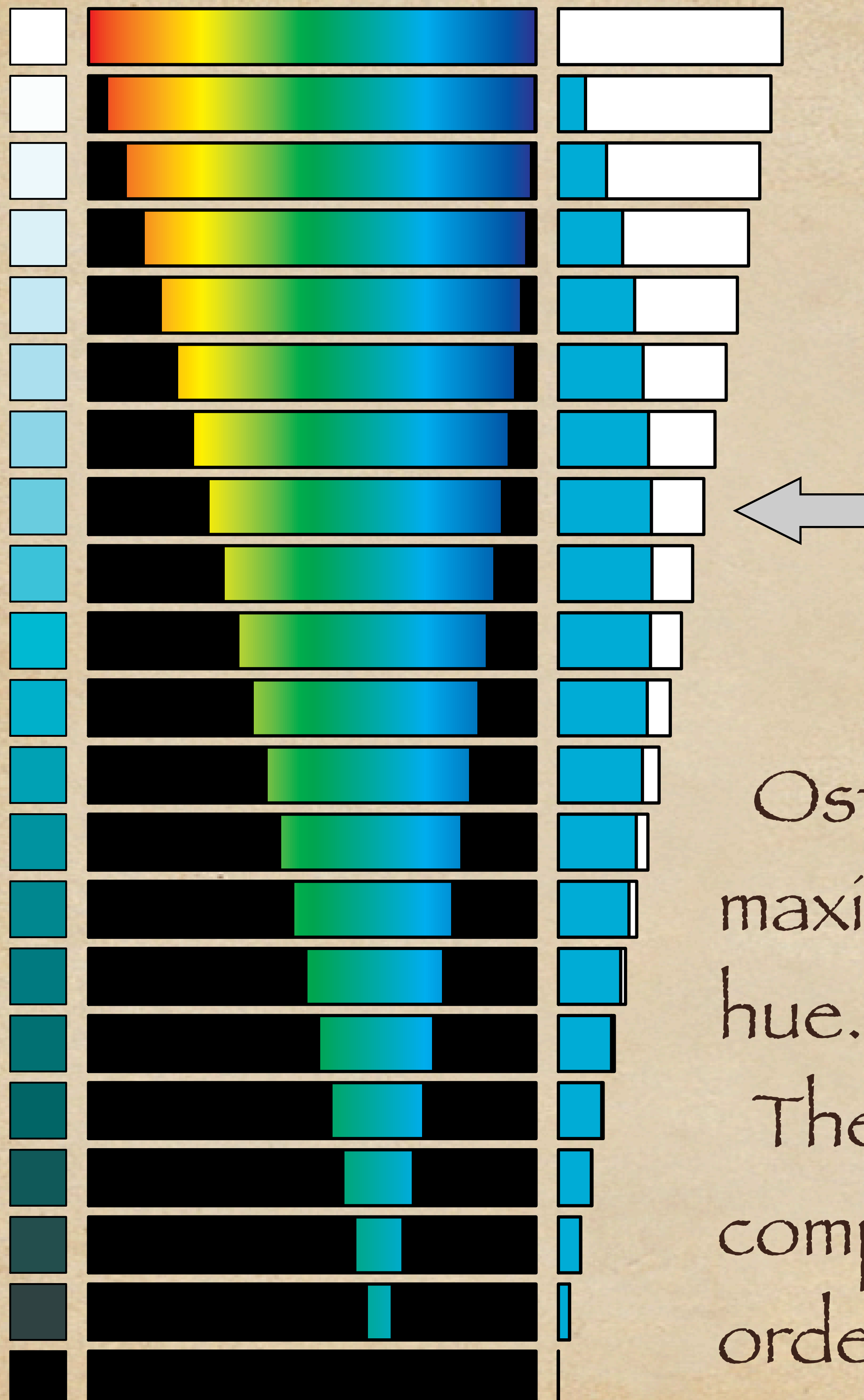


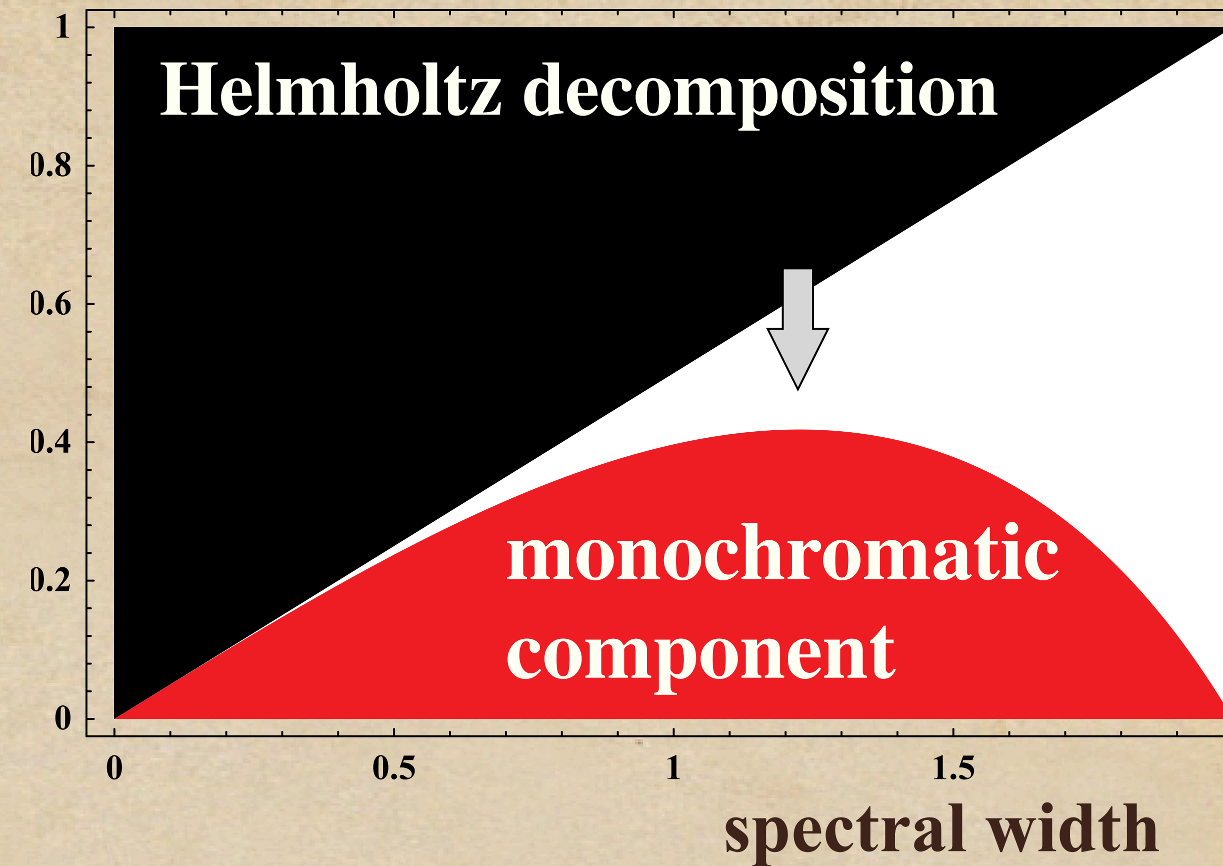
The cardinal colors as "parts of daylight"





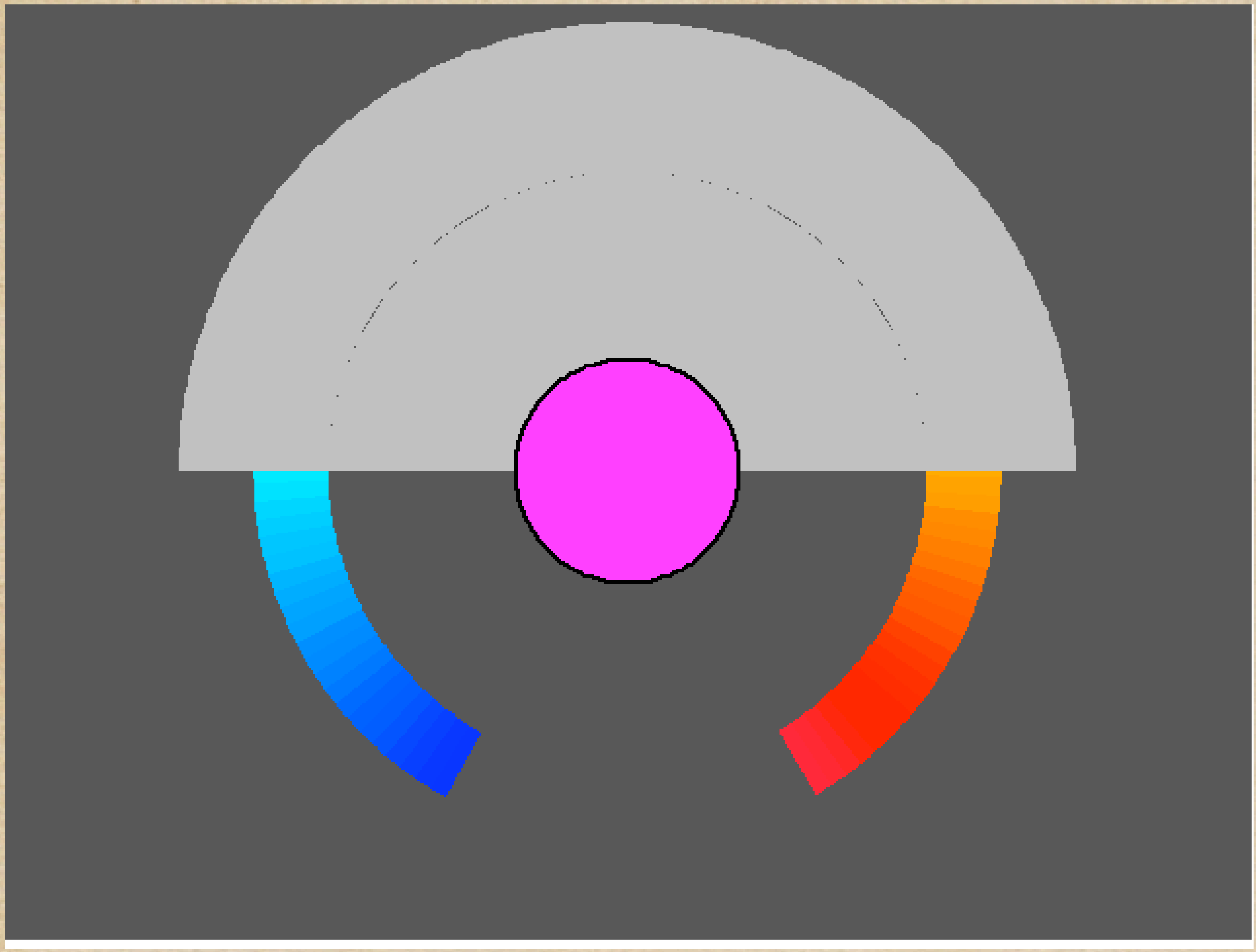
Ostwald also thinks of the full colors as "parts of daylight". Indeed the semichromes are "half of daylight". Because he curved the spectrum the purples appear as "natural parts". Unlike Newton Ostwald retains the "gap".



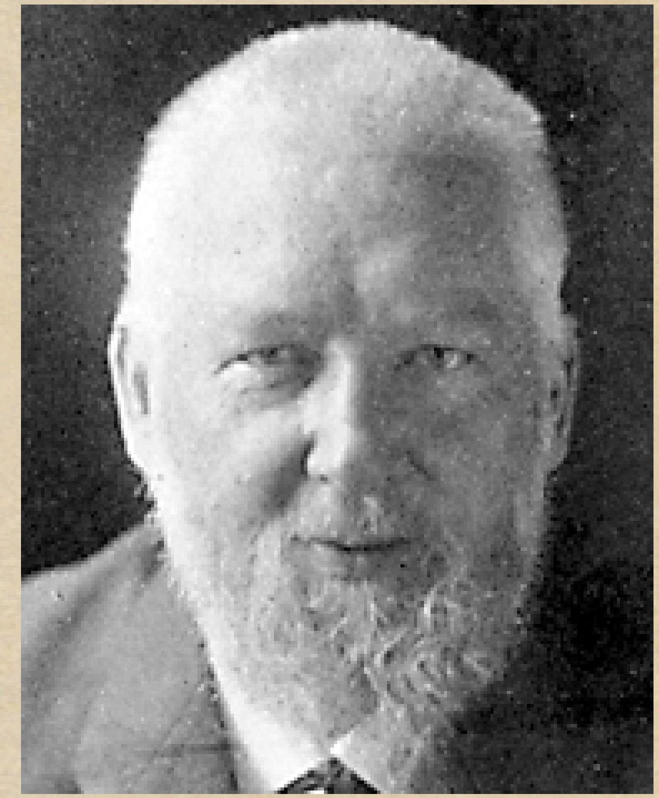


Ostwald's "full colors" have maximum color content for a given hue.

The band limits have to be at complementary wavelengths in order to obtain the maximum.

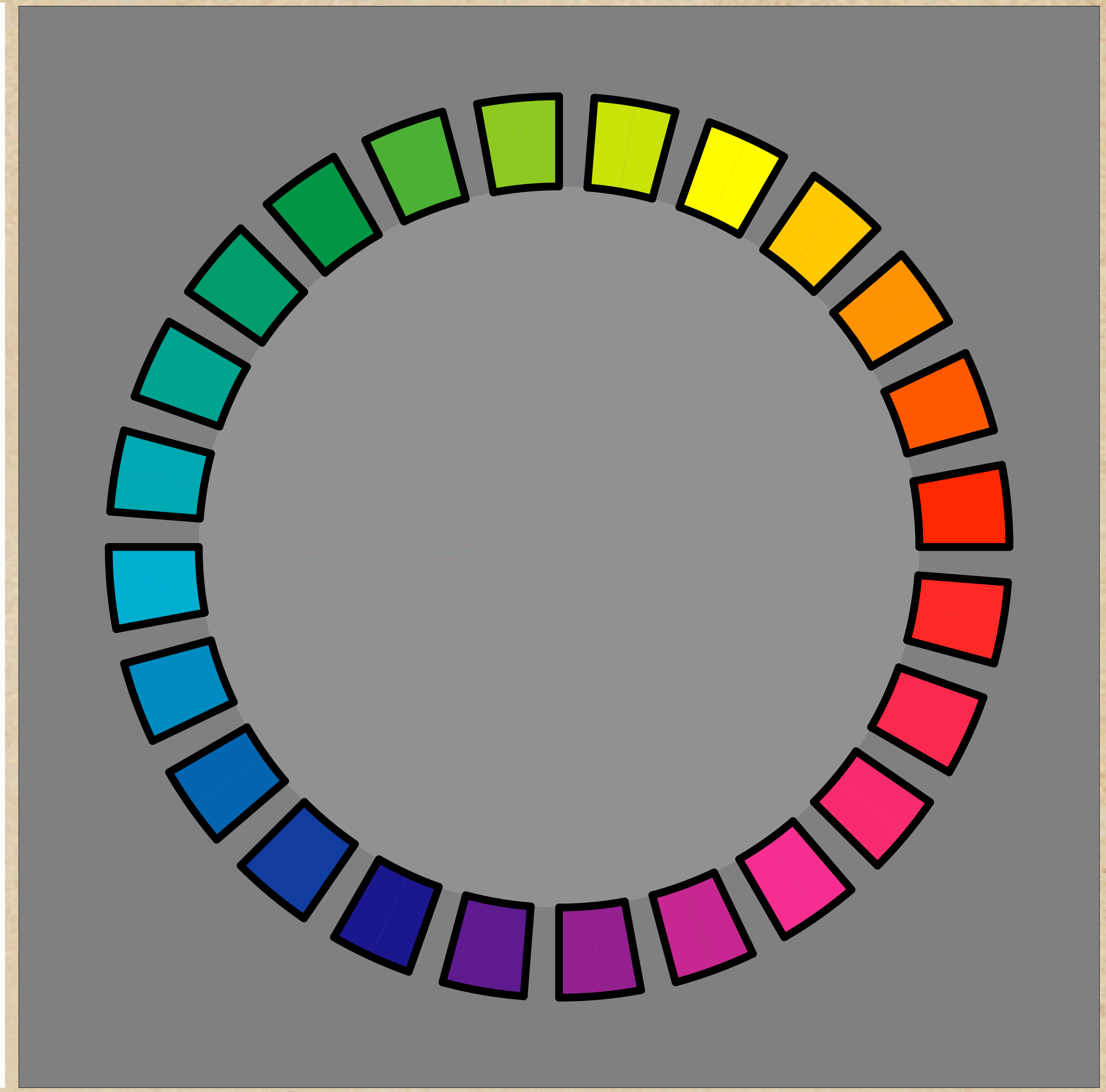


Ostwald's "semichromes"

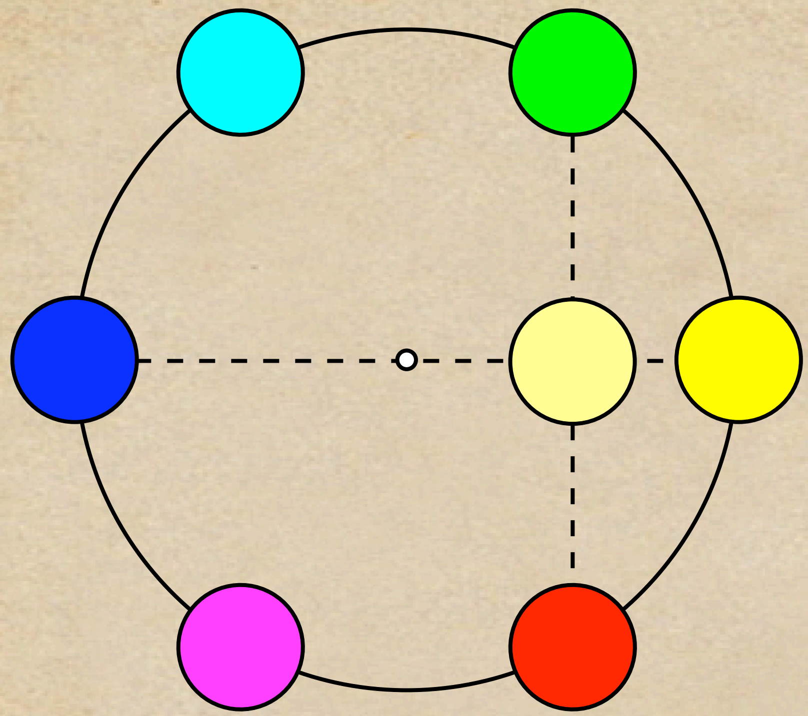


The relation between the color circle and the spectrum is explained through Ostwald's construction of the "semichromes". The semichromes are also full colors.

The Mensuration of the Color Circle

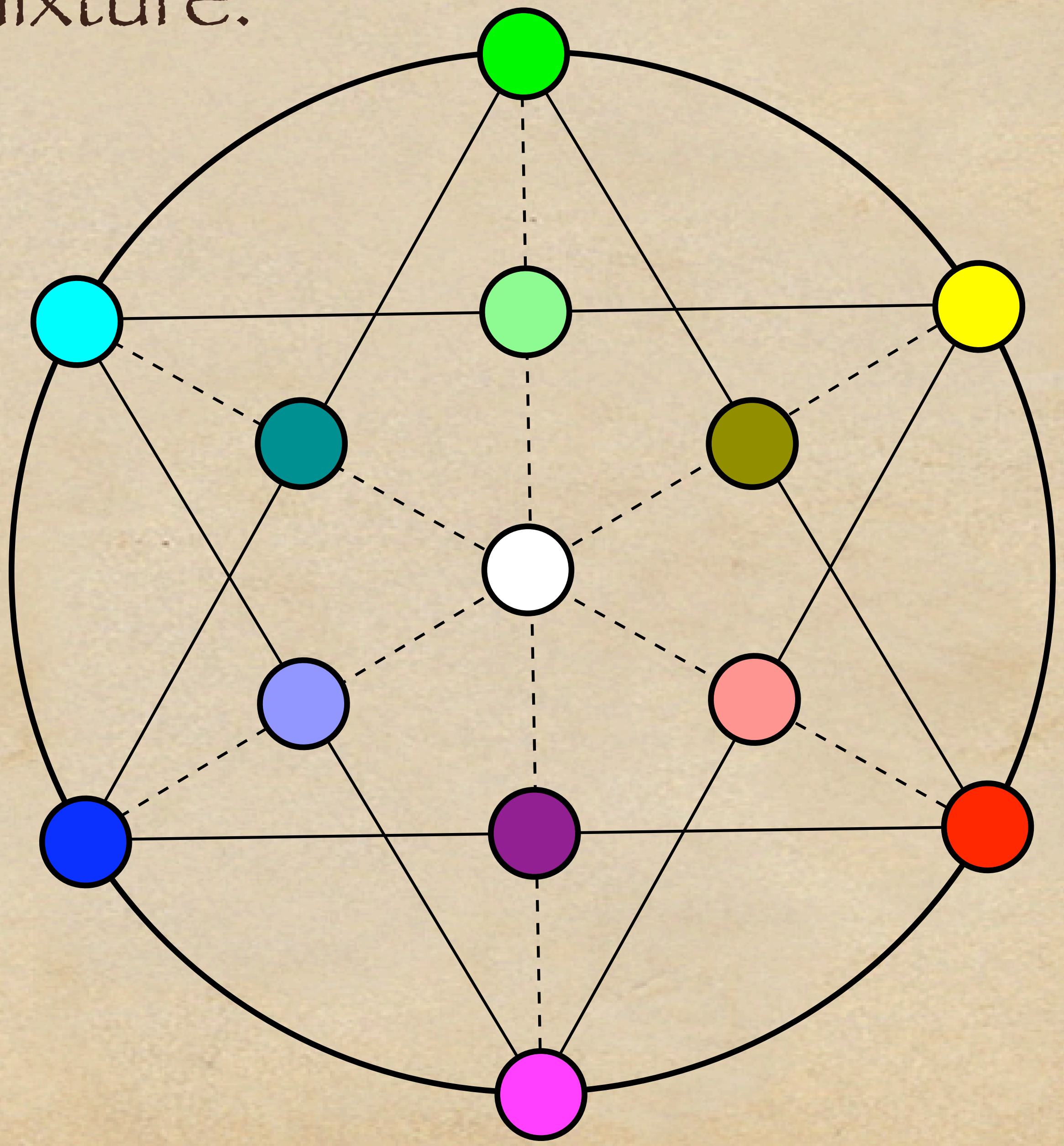


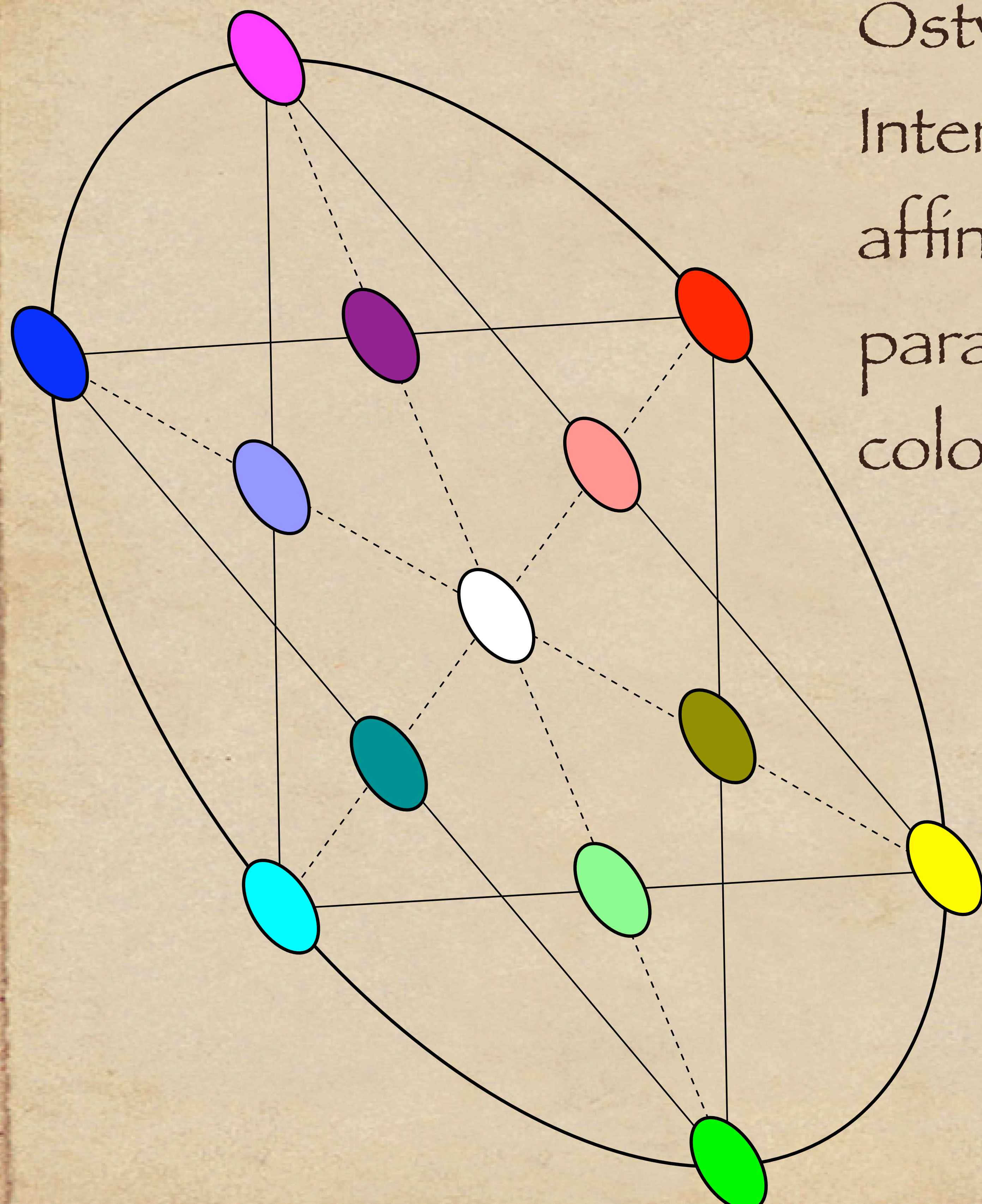
The color circle is only a topological circle, without a metric. One would like to fit it with a "well tempered scale". Ostwald pioneered a method to do this.



Ostwald's "Principle of Internal Symmetry" is very simple: Define bisection of line elements through equal mixture.

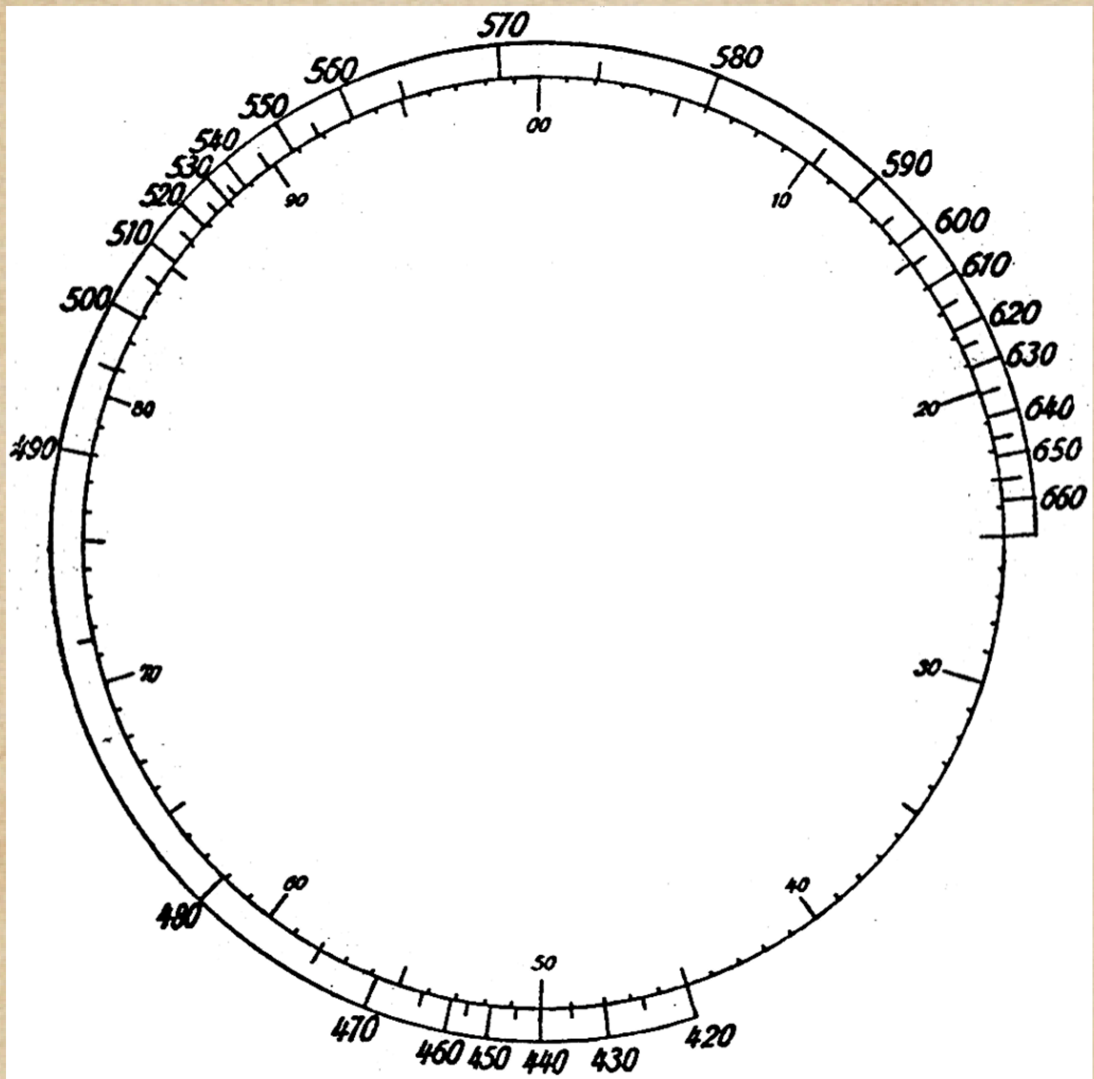
Here the RGB color circle is mensurated: Starting with the primary colors R, G and B, one obtains the secundary colors C, M and Y. Going the other way one obtains C, M and Y from R, G and B. The whole system is internally consistent.

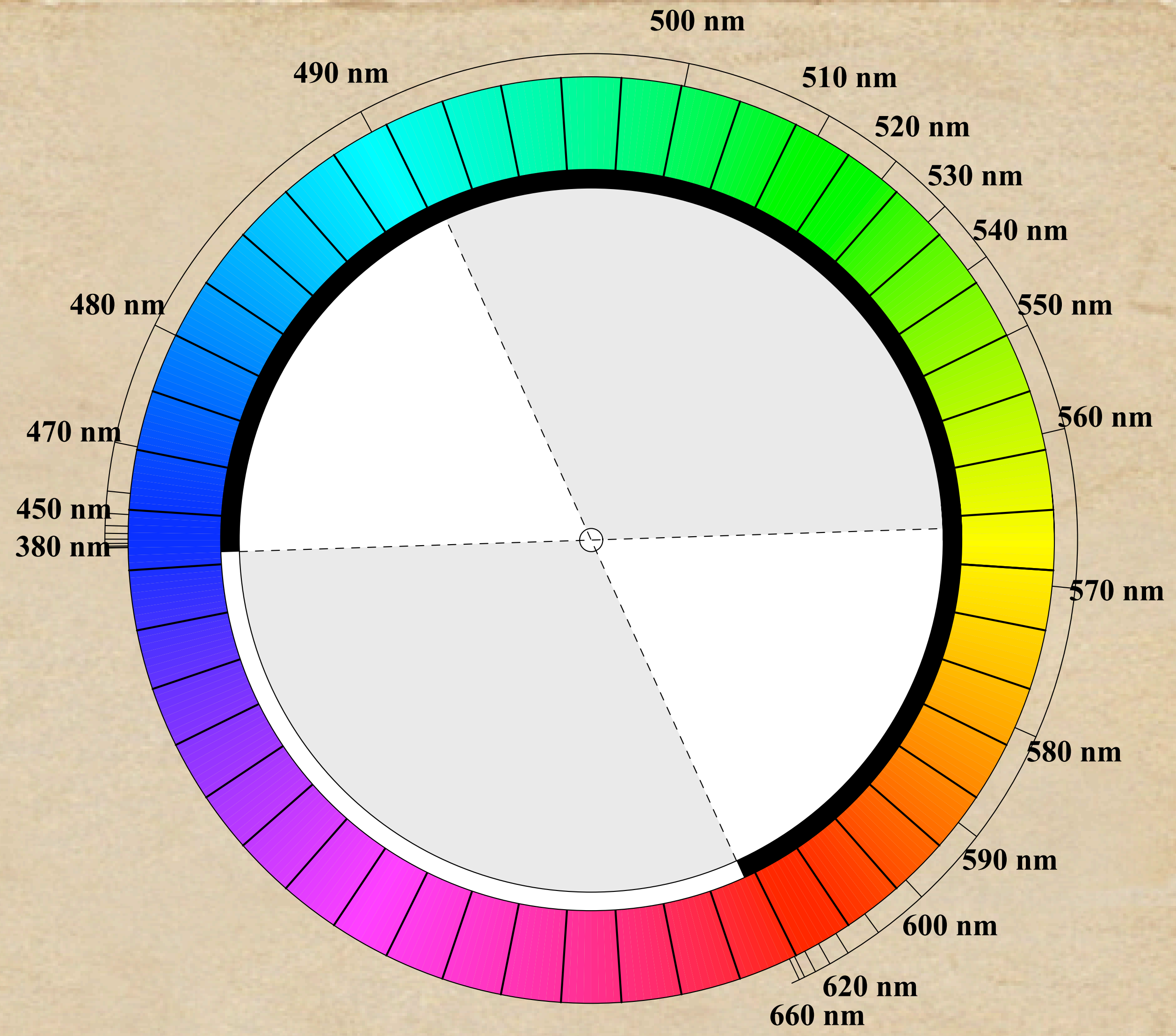




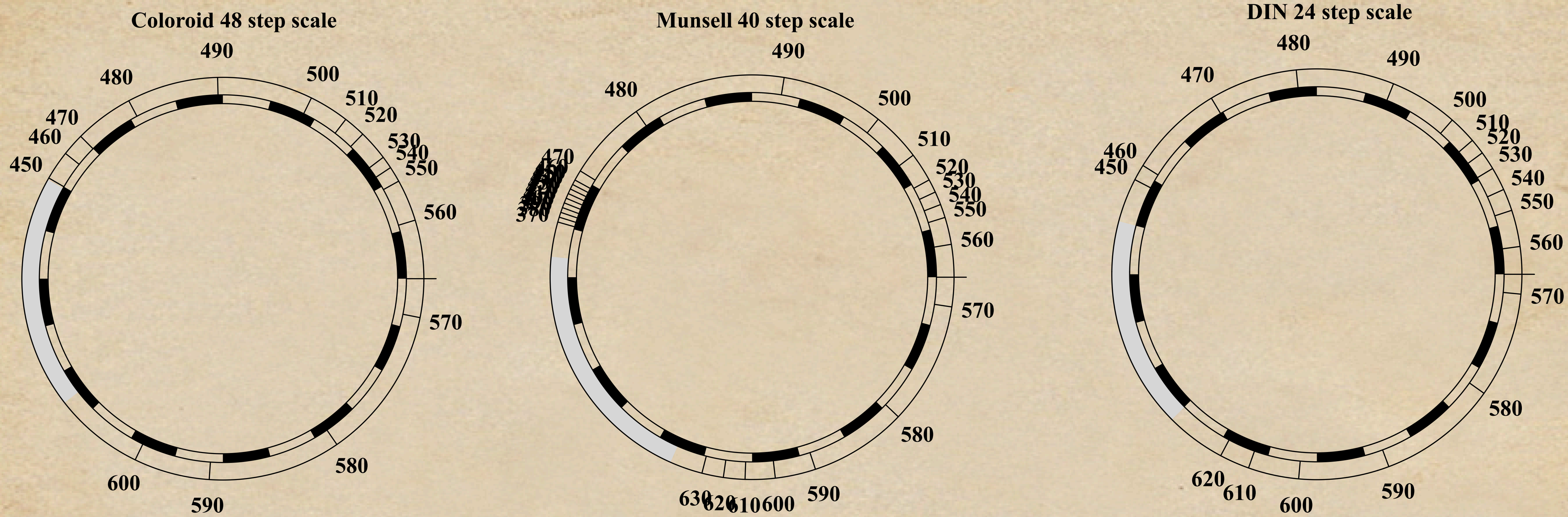
Ostwald's "Principle of Internal Symmetry" yields an affinely invariant arc length parameterization of the color circle.

The first colorimetric (numerical) calculations were by Bouma in the 1940's (now forgotten).





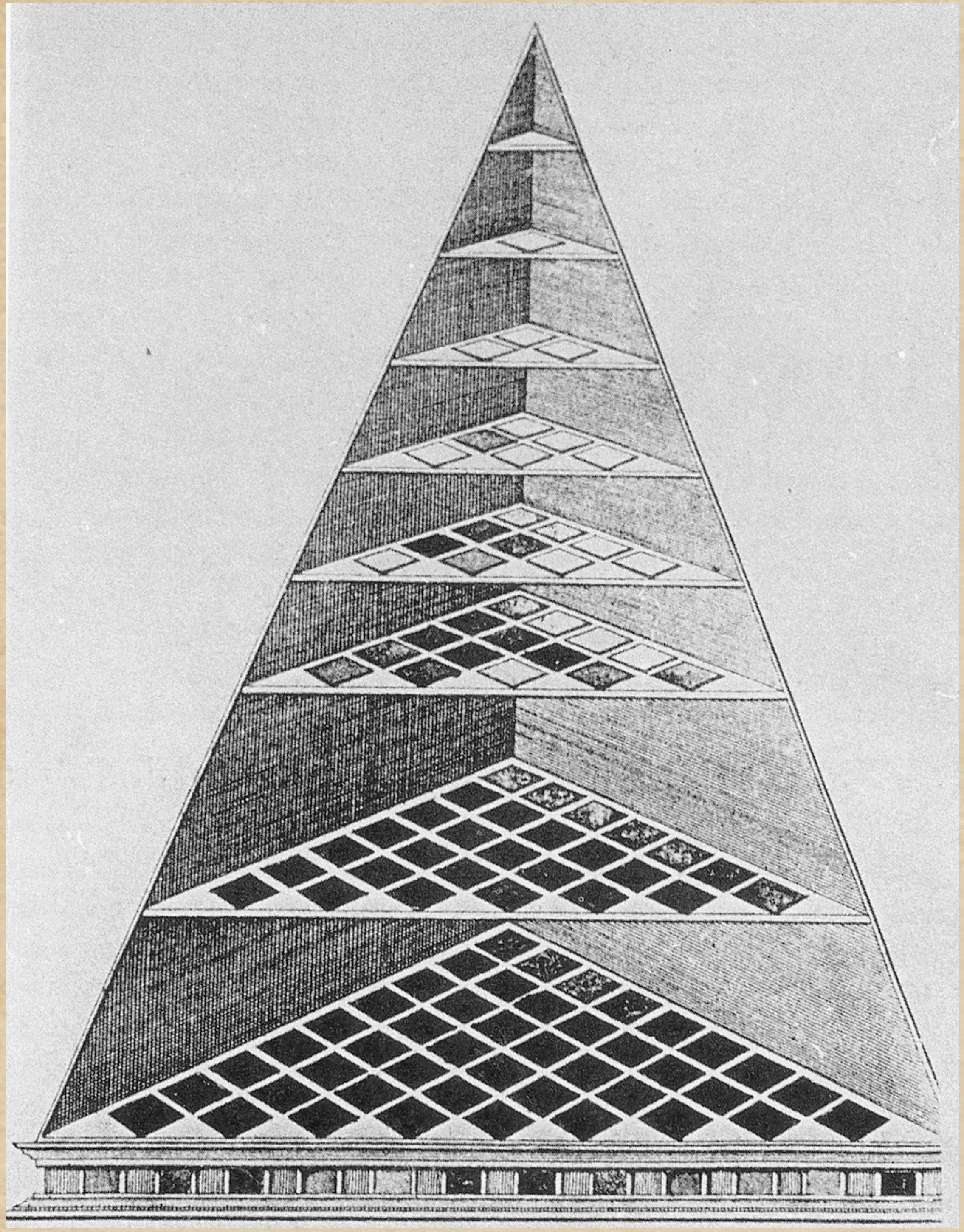
Left an example of the mensurated color circle by Ostwald. Right a mensurated color circle calculated (using the CIE 1964 standard observer) from modern data for average daylight (CIE D75).



Psychological ("Eye Measure") Scales

Empirically, the Ostwald mensuration "predicts" the eye measure scales quite well. This is most remarkable because it requires mere colorimetric (objective) data. (Only judgments of equality, no absolute color judgments!) Psychology is not involved.

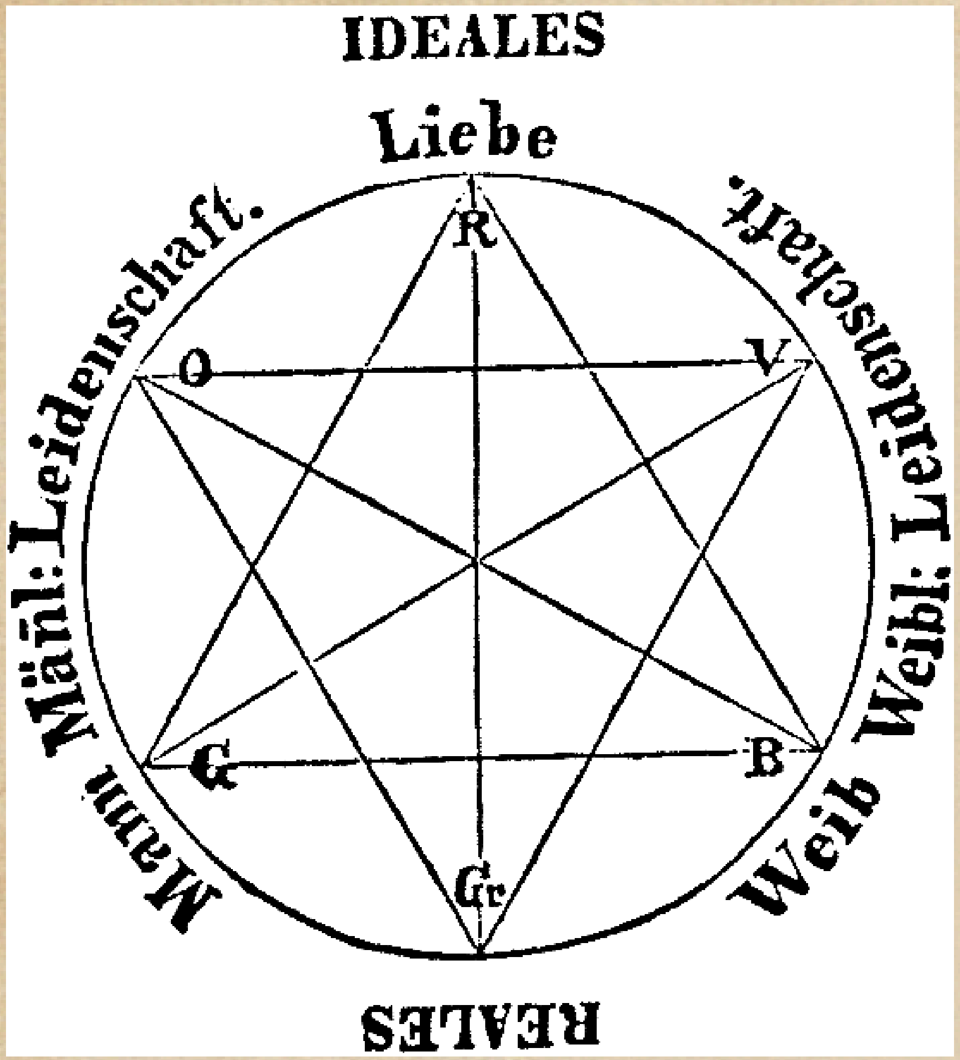
The Structure of the Object Color Solid



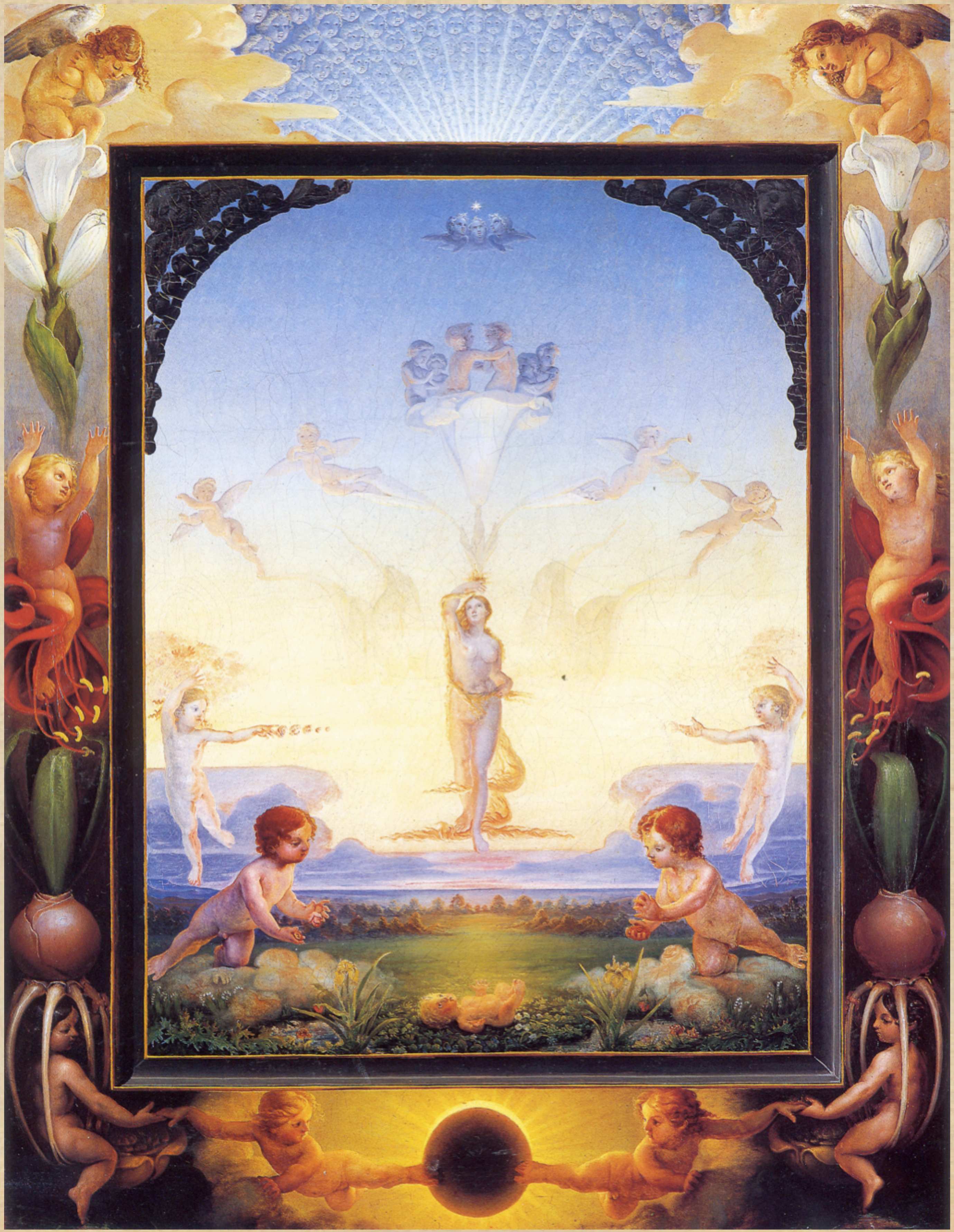
Lambert 1772

Of the many attemps to systematize the object colors before Runge (1834) none came up with the correct topology.

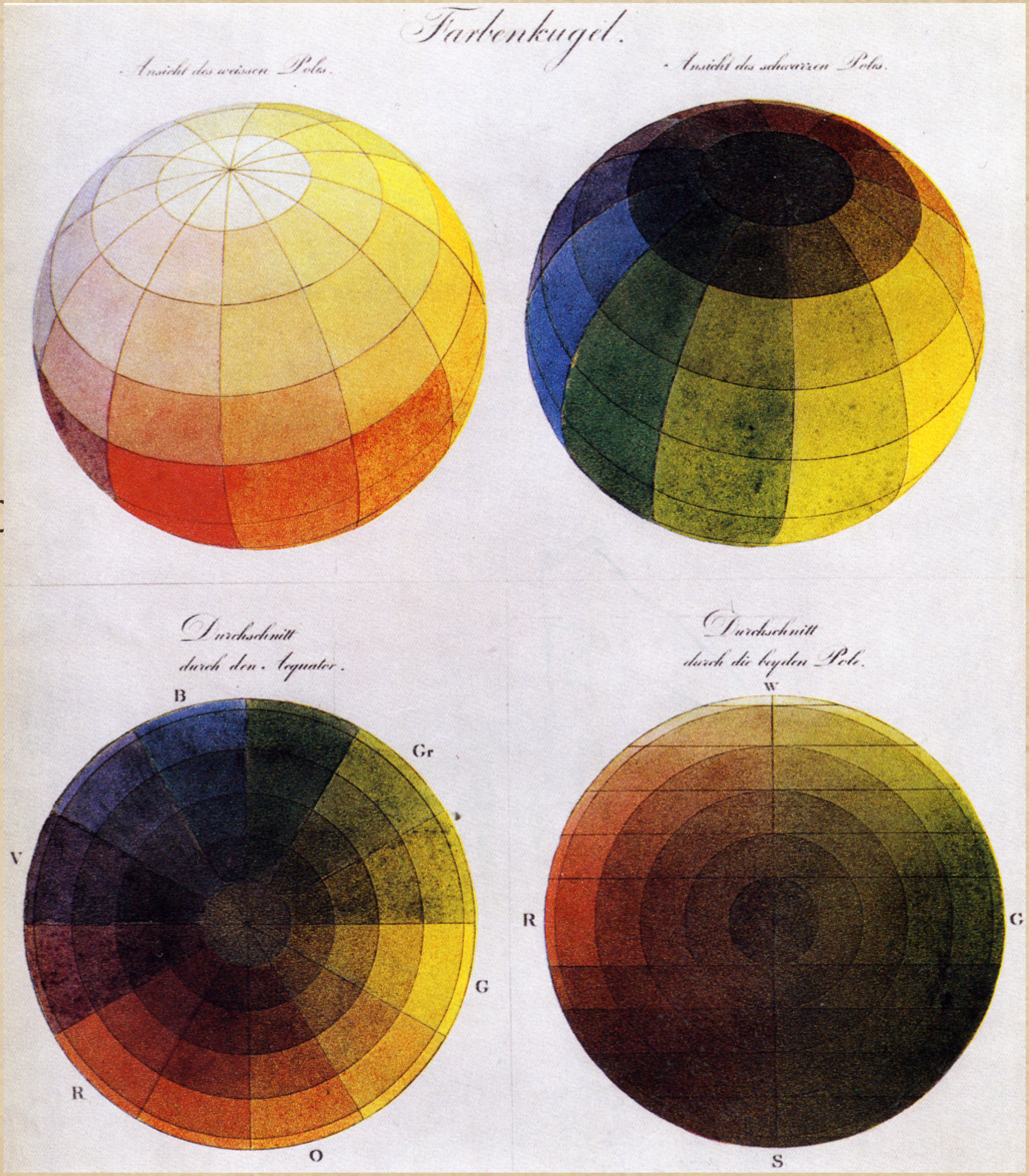
The modern theory of the color solid is due to Erwin Schrödinger (Ann.Physik 1920).

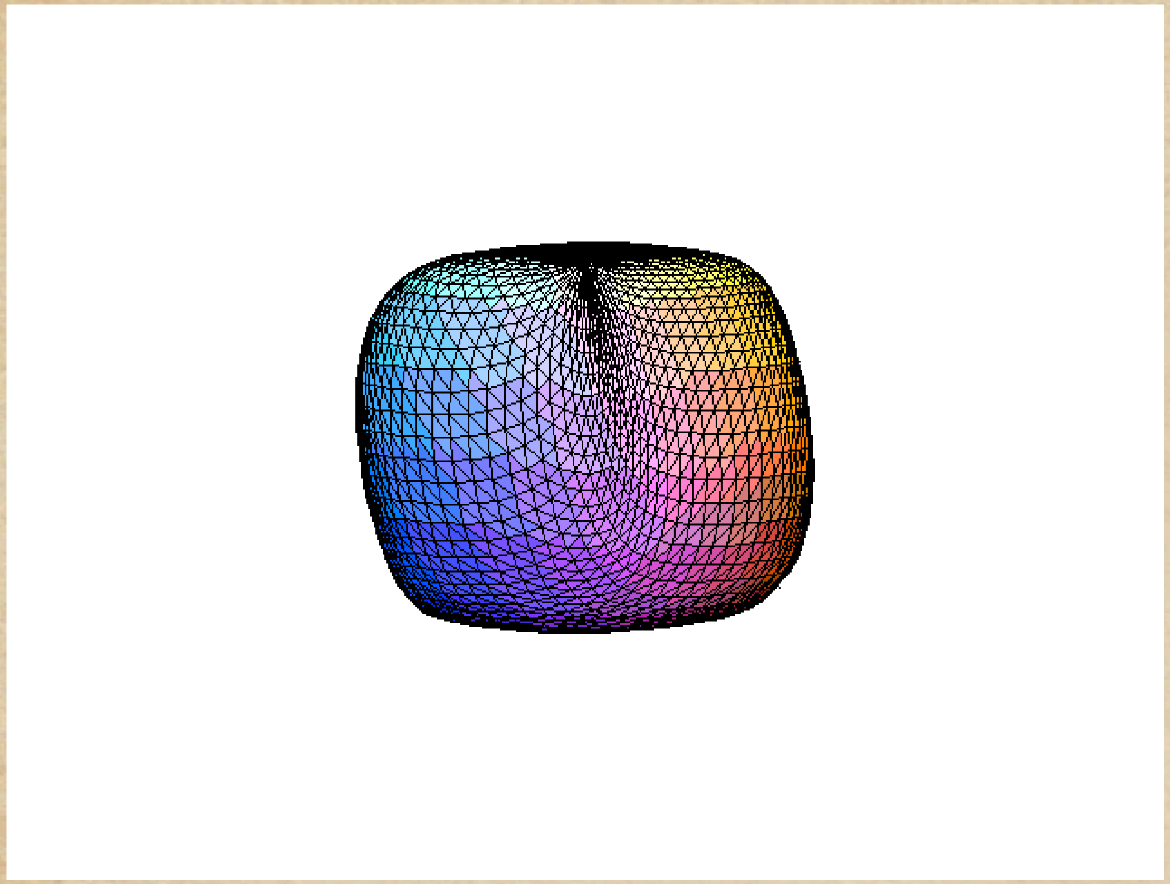


Philip
Otto
Runge

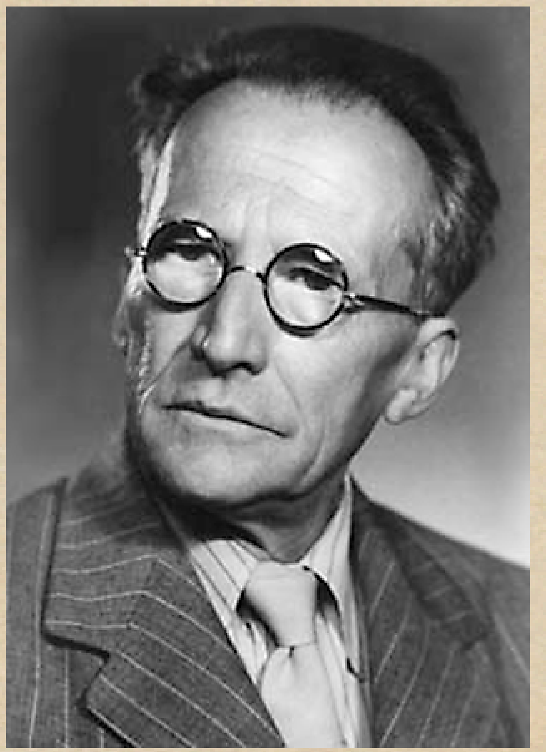


Runge came up with the first "color solid" of the correct topology. ("Farbenkugel", 1834)

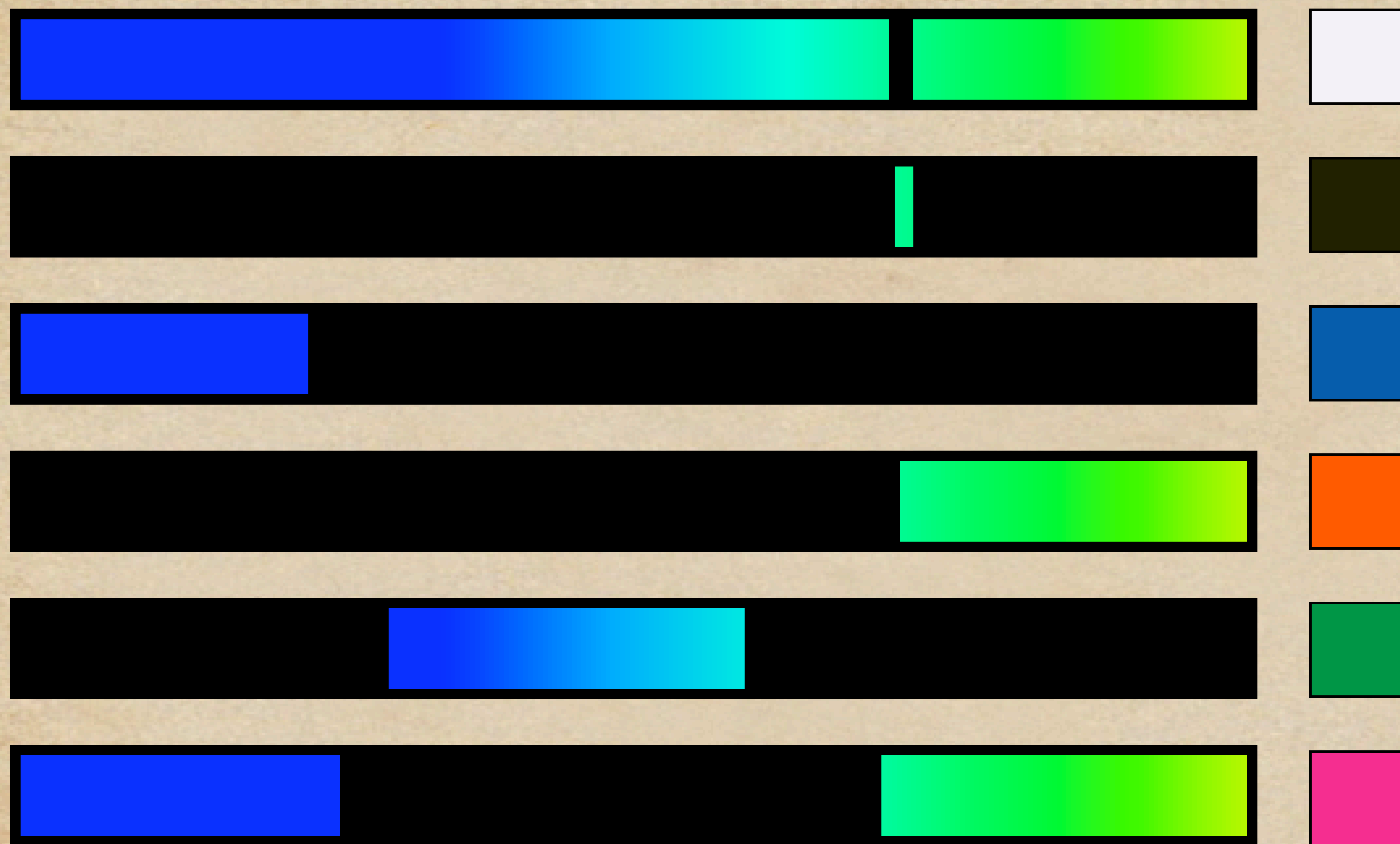




The Schrödinger "color solid".



All object colors lie within a finite, convex volume. Its boundary is smooth, except for two points: At the black point the solid is tangent to the spectrum cone, at the white point to the inverted spectrum cone.

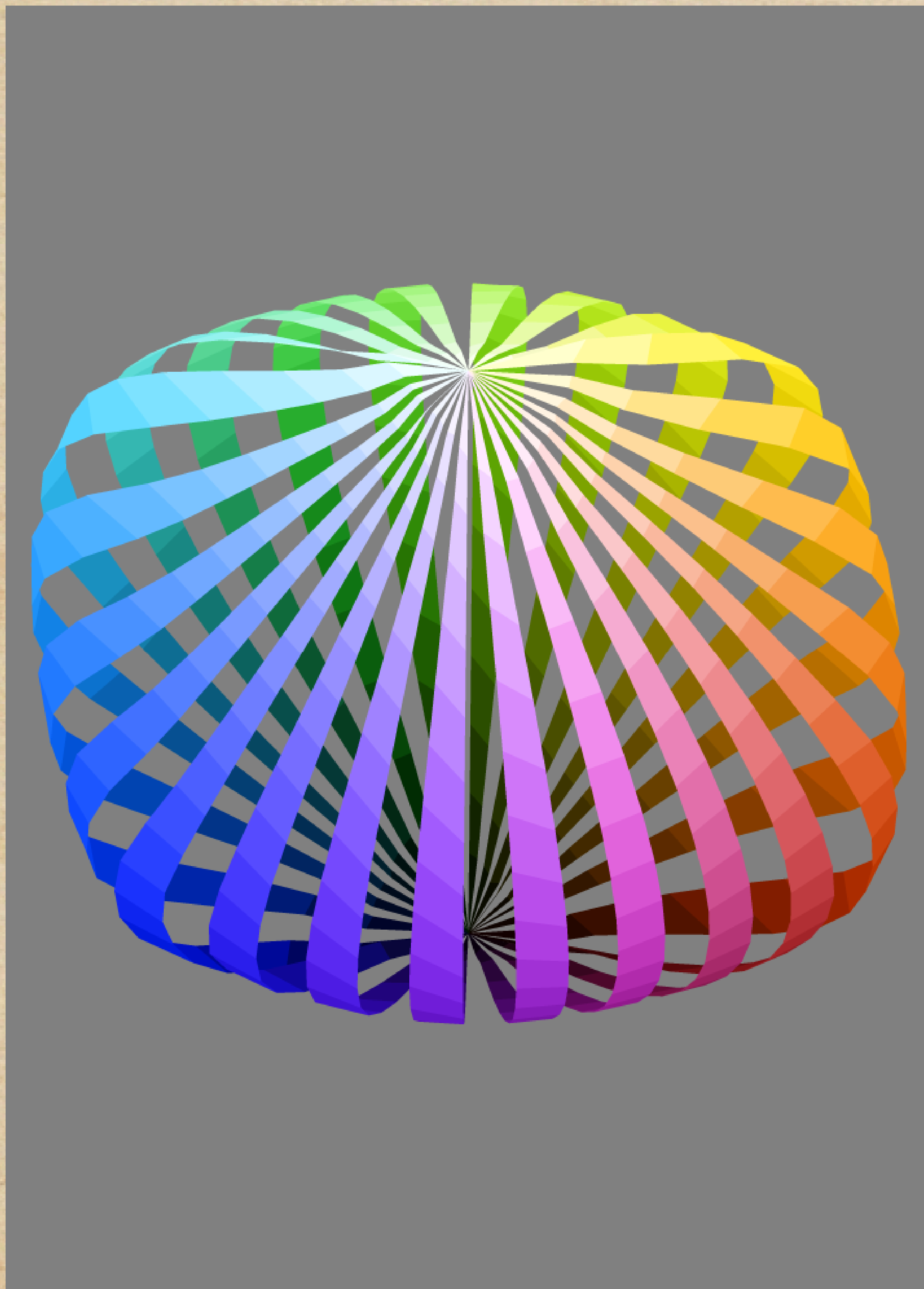


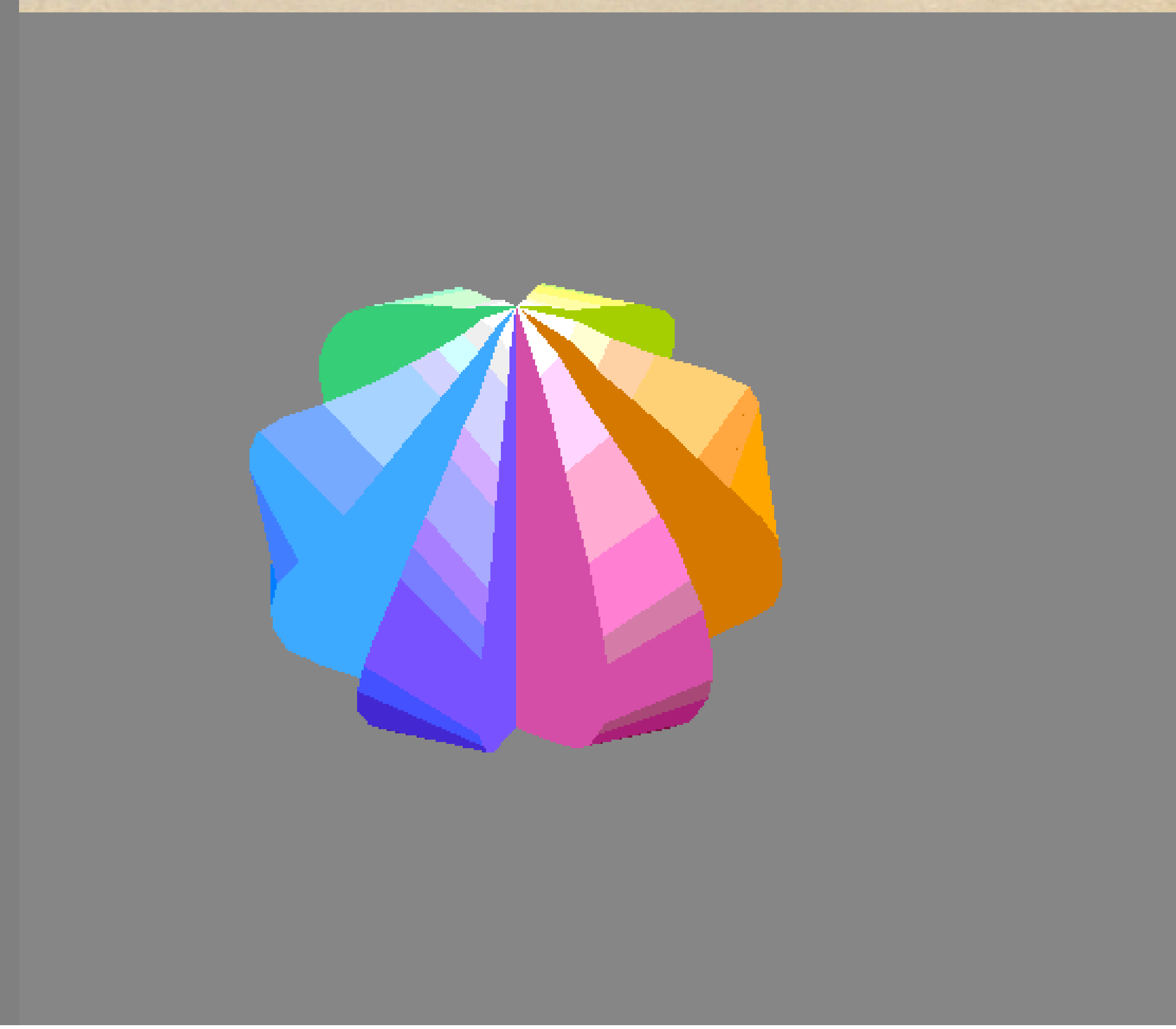
off-white
black (monochromatic)
highpass edge color
lowpass edge color
bandpass (spectral)
bandgap (non-spectral)

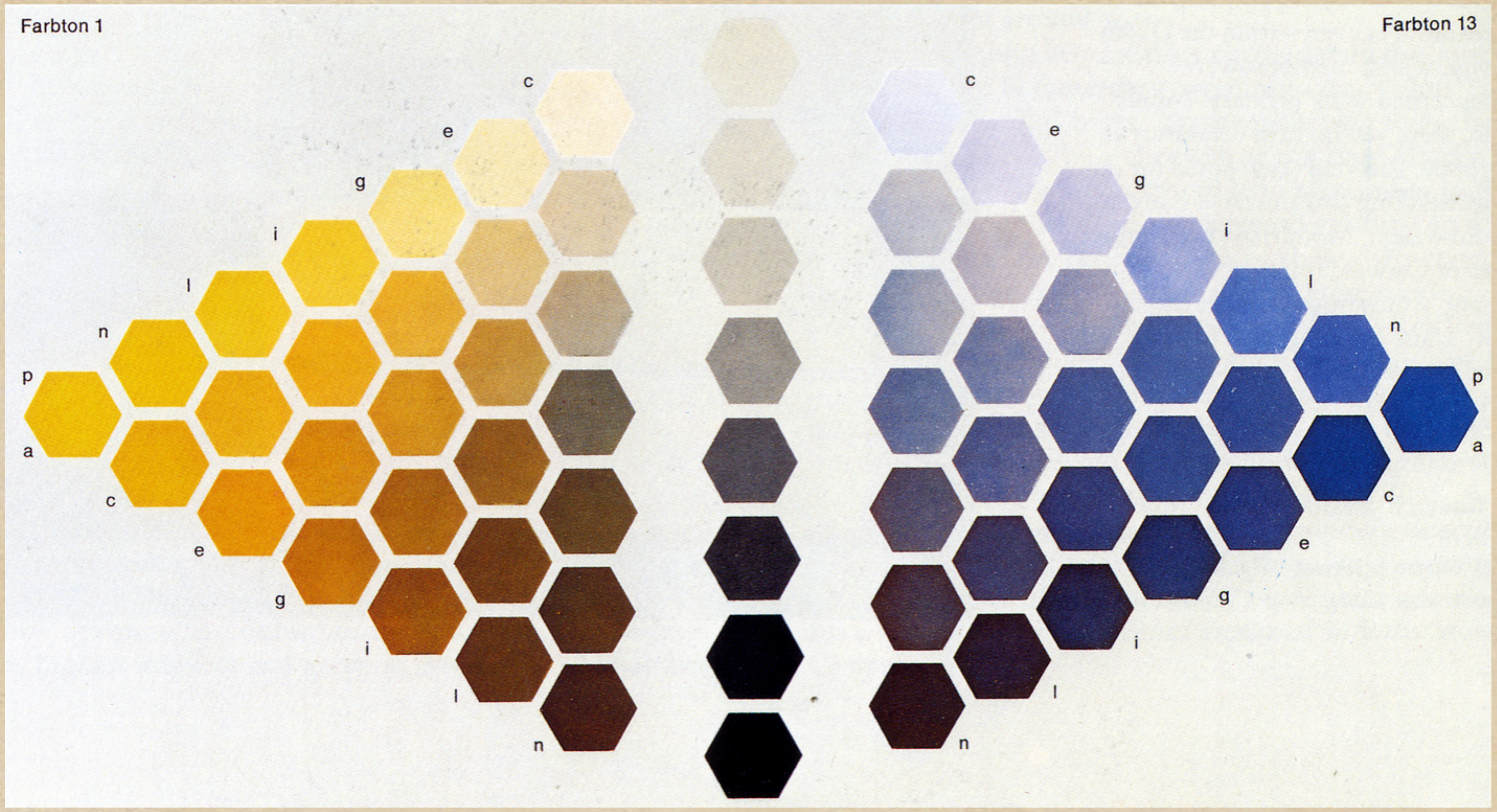
The Schrödinger "optimal colors" make up the boundary of the color solid. They are the brightest colors for any given chromaticity (the best paints, containing no gray).

The most colorful optimal colors are the Ostwald full colors.

Schrödinger's color solid mensurated via Ostwald's "principle of Internal Symmetry": A fully objective framework.

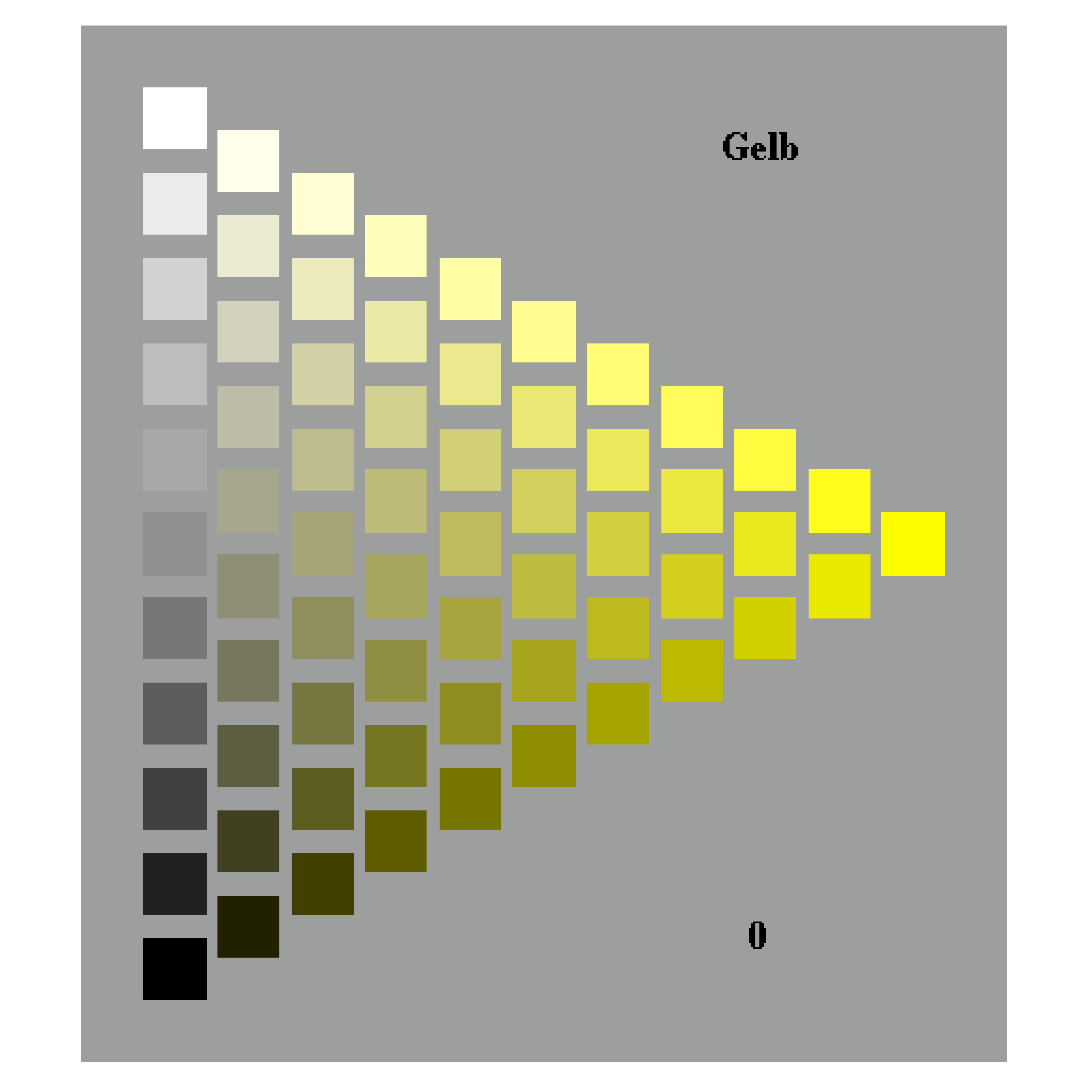






Ostwald conceived of object colors as partitive mixtures of white, black, and a full color. Placing the gray axis perpendicular to the center of the (full-) color circle, he arrived at a double cone.

example of an Ostwald atlas double page computed for the RGB colors



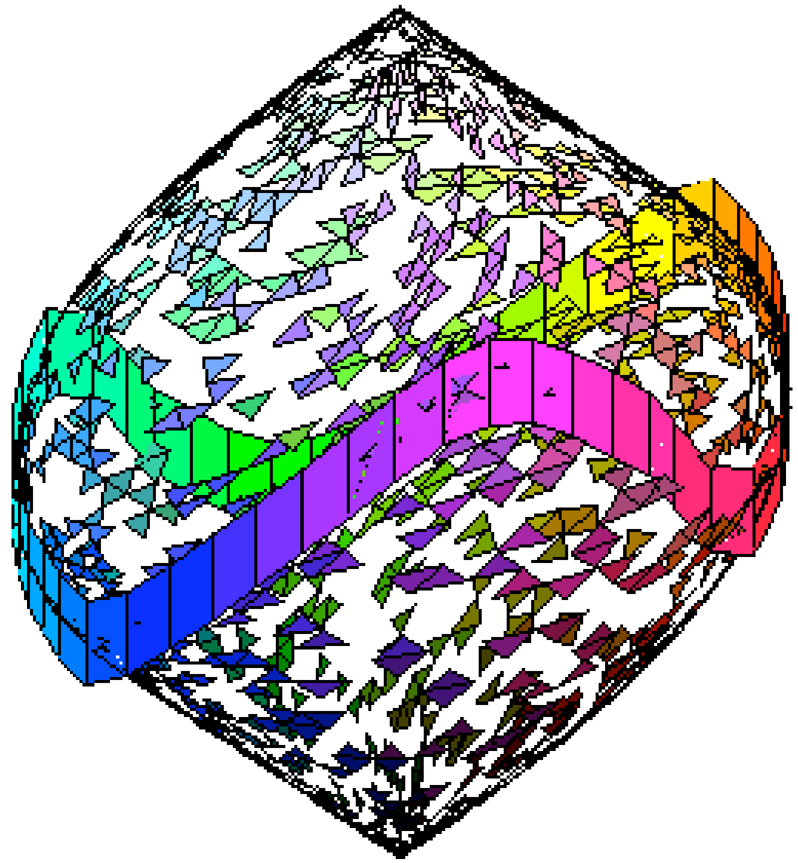
This atlas is based on a 24 hue color circle.

Notice the idiosyncratic hue names assigned by Ostwald.

white pole

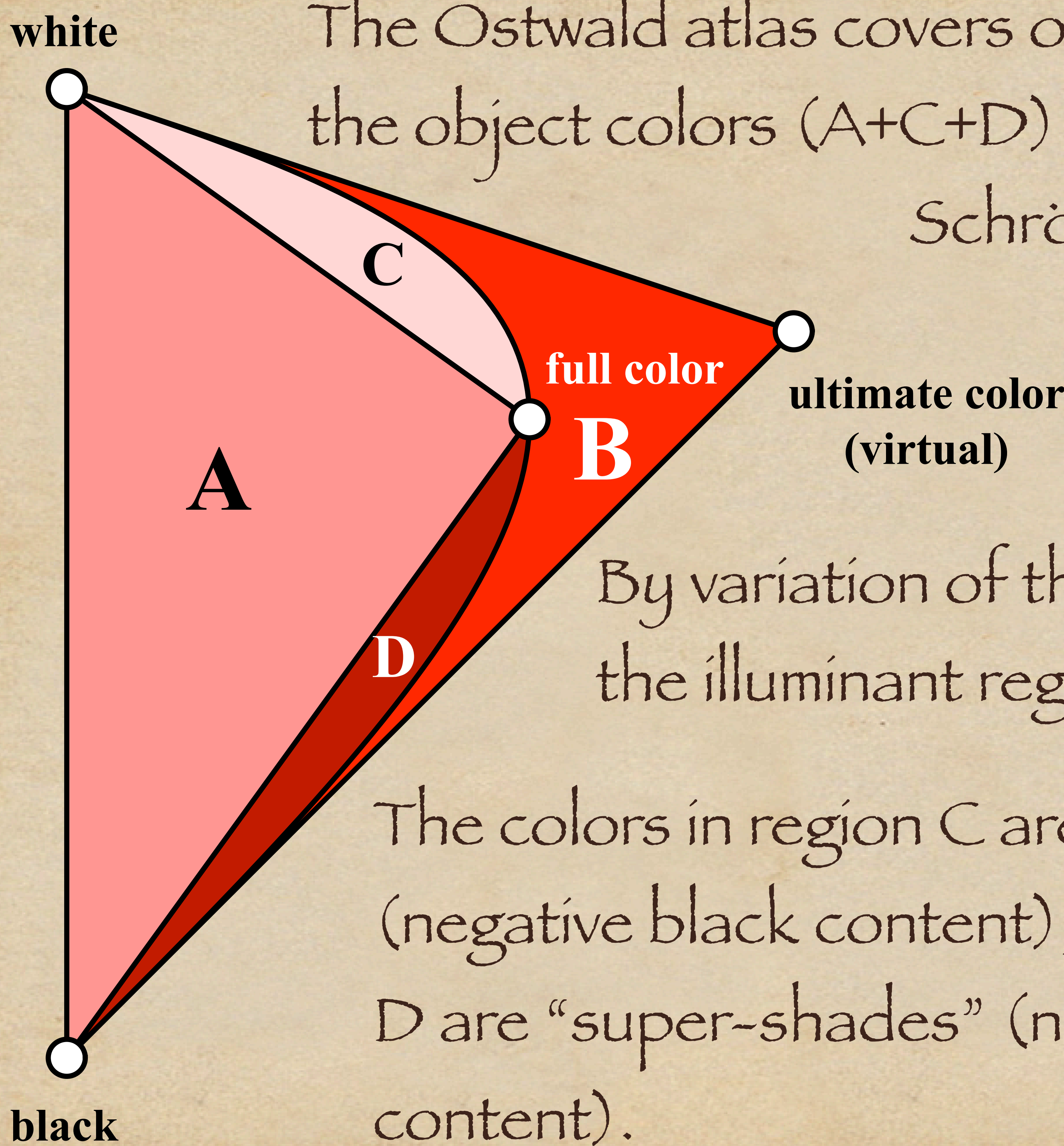
ribbon of full colors

not a planar "color circle!



black pole

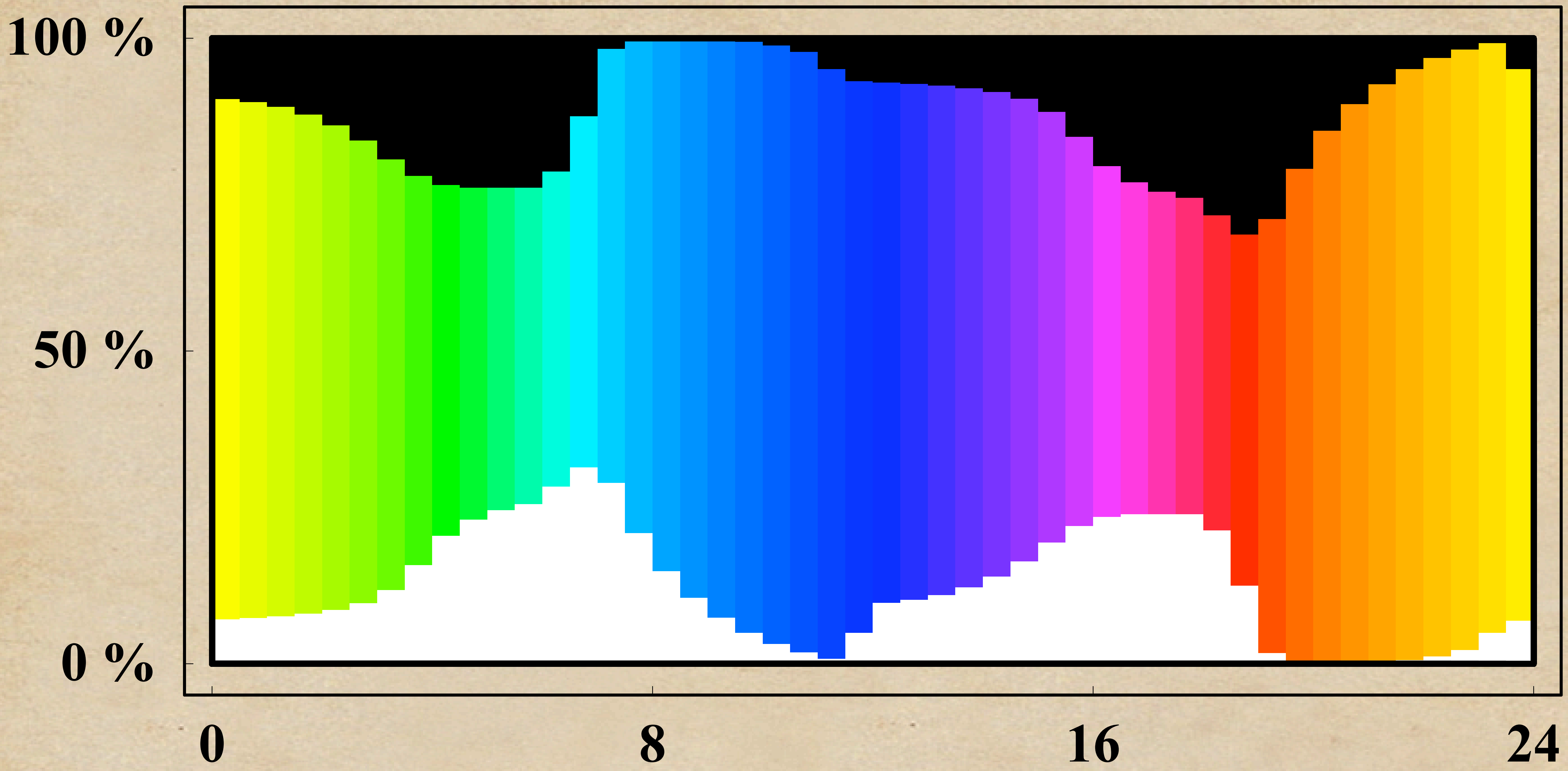
In the Schrödinger color solid the Ostwald full colors ("Vollfarben") are at greatest distance from the gray axis.



The Ostwald atlas covers only part (A) of the object colors (A+C+D) as derived by Schrödinger (1920).

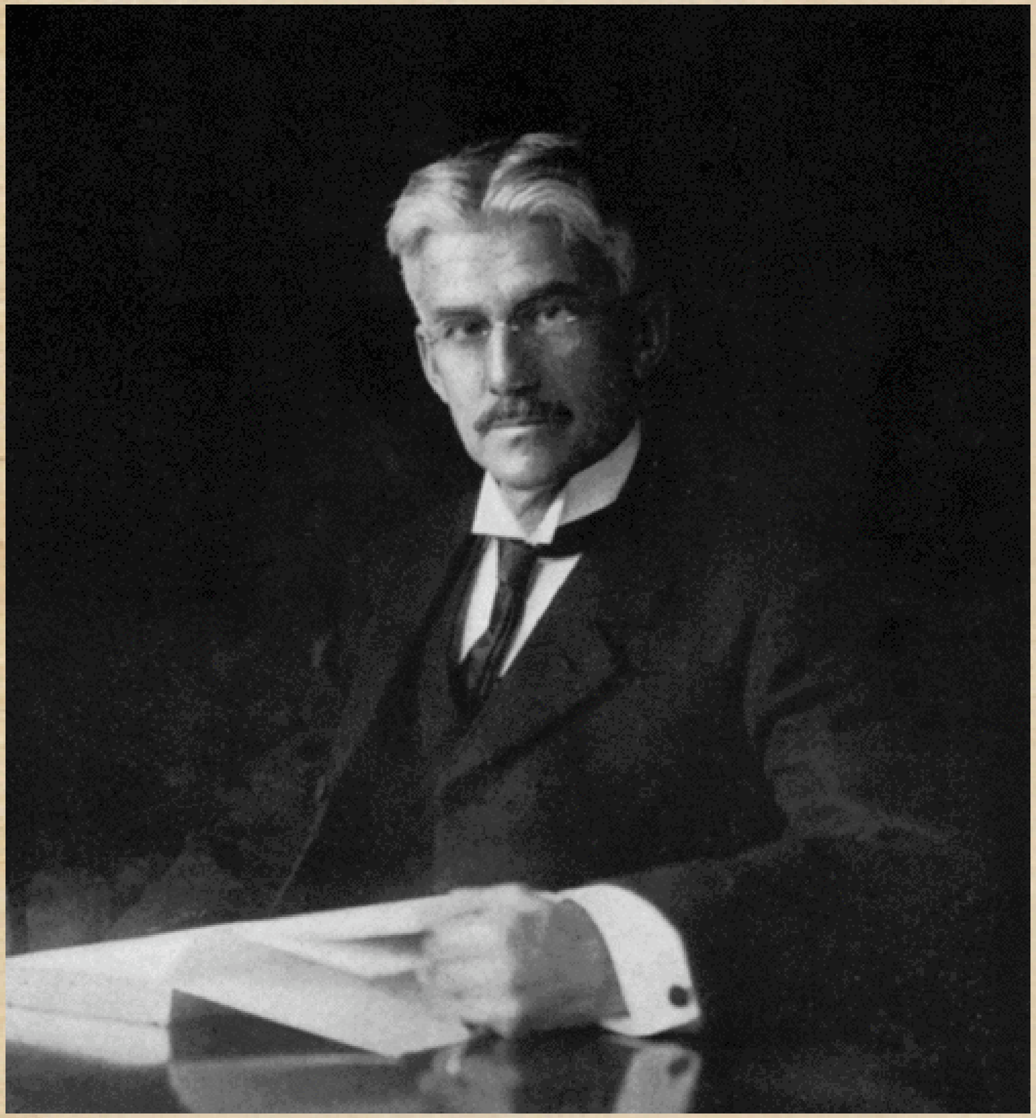
By variation of the spectrum of the illuminant region B is available.

The colors in region C are "super-tints" (negative black content), those in region D are "super-shades" (negative white content).



In terms of the ultimate colors the full colors themselves can be analyzed in terms of their color, white and black content! The "best" colors are blue and yellow, "worst" are cyan and magenta.

The Colorimetric Color Atlas

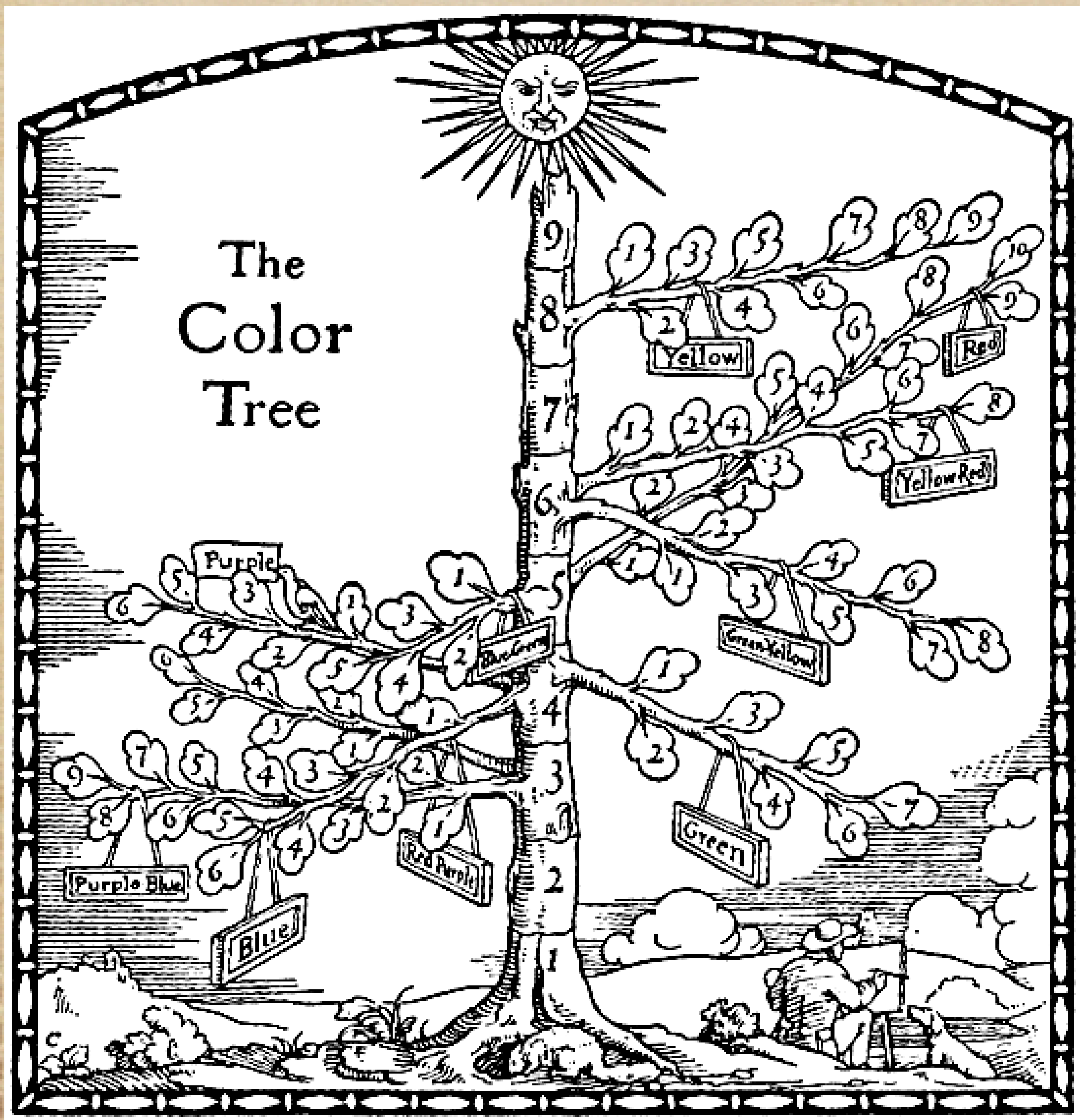


Albert Munsell

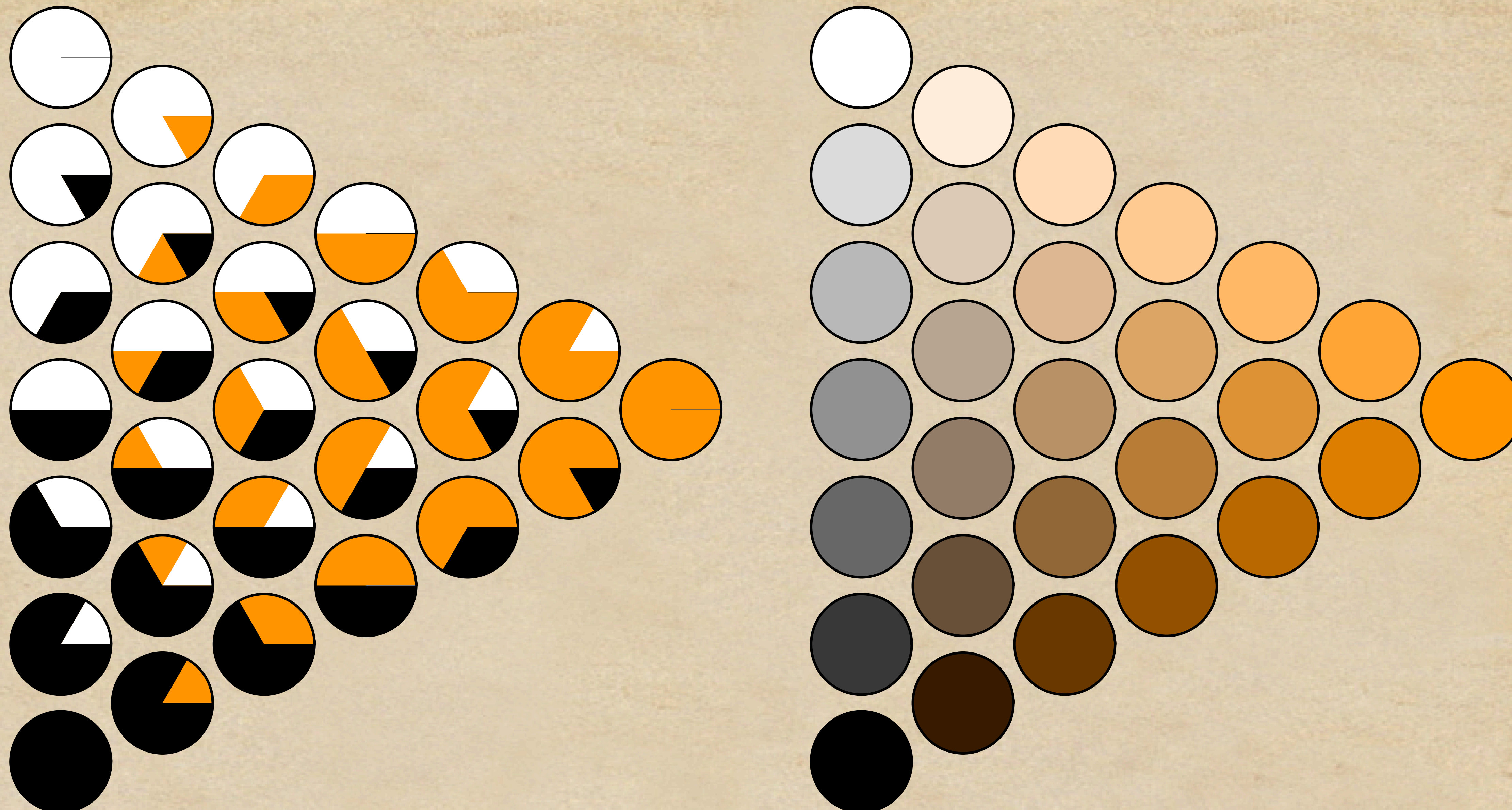
Albert Munsell (a painter) worked on a "color atlas" almost simultaneously with Ostwald. (The two met.)

In the final instance, Munsell reverted to "eye measure" to arrive at a metric.

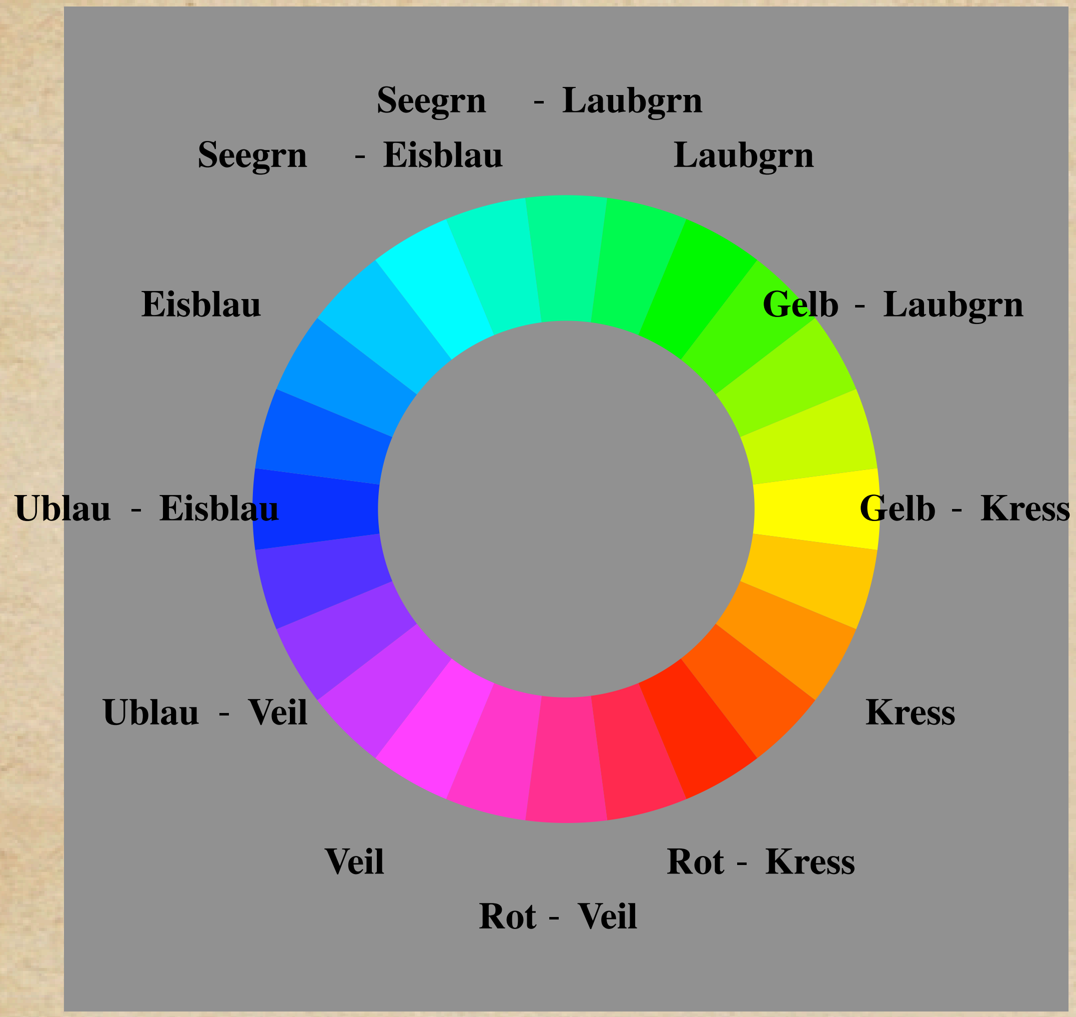
Thus the "Munsell-system" stands well apart from colorimetry proper.

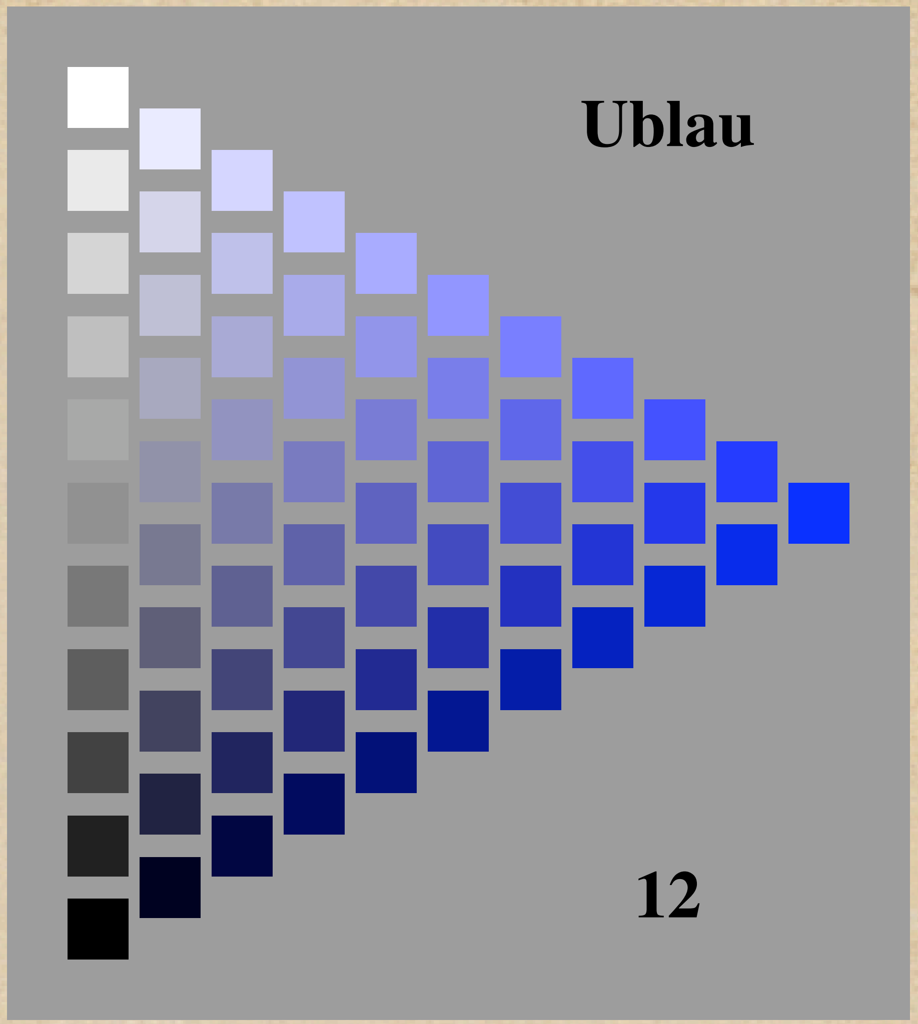


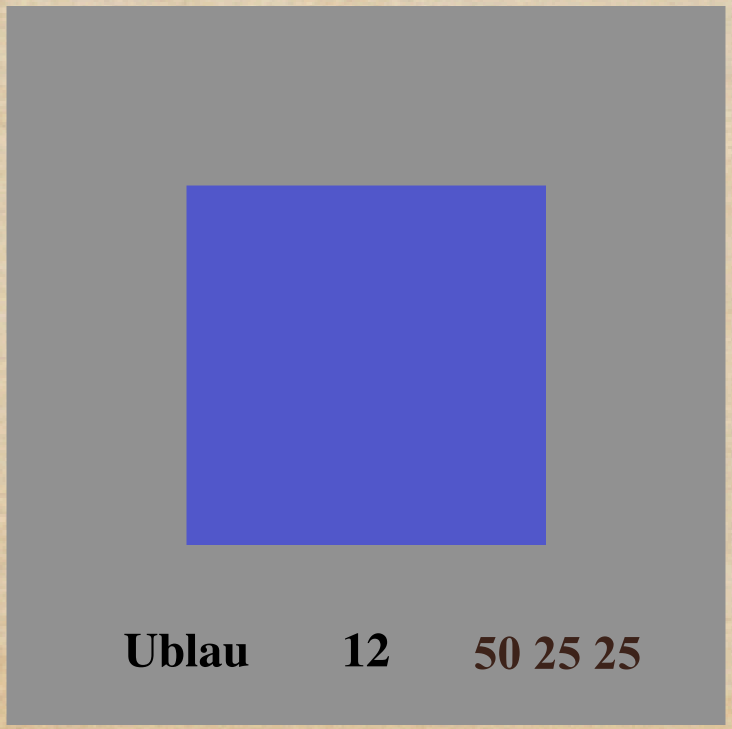
Munsell's concept of a "color tree" is a cylindrical coordinate system based on the gray axis.
There is no fundamental limit to the distance the "branches" may go.
This fully ignores the colorimetric basis.



Construction of a page of the Ostwald atlas. The samples can be generated by simple means (Ostwald used the POMI, HASCH and inverted spectroscope). This (in principle) involves NO EYE MEASURE.







A sample from the Ostwald atlas:

Full color #12 (Ublau),

50% color, 25% white, 25% black.

By far the best way to memorize, select, or indicate colors is by way of their hue and color, white and black contents.

With some practice one learns to "see" these parameters.

Modern application: "Color Pickers"

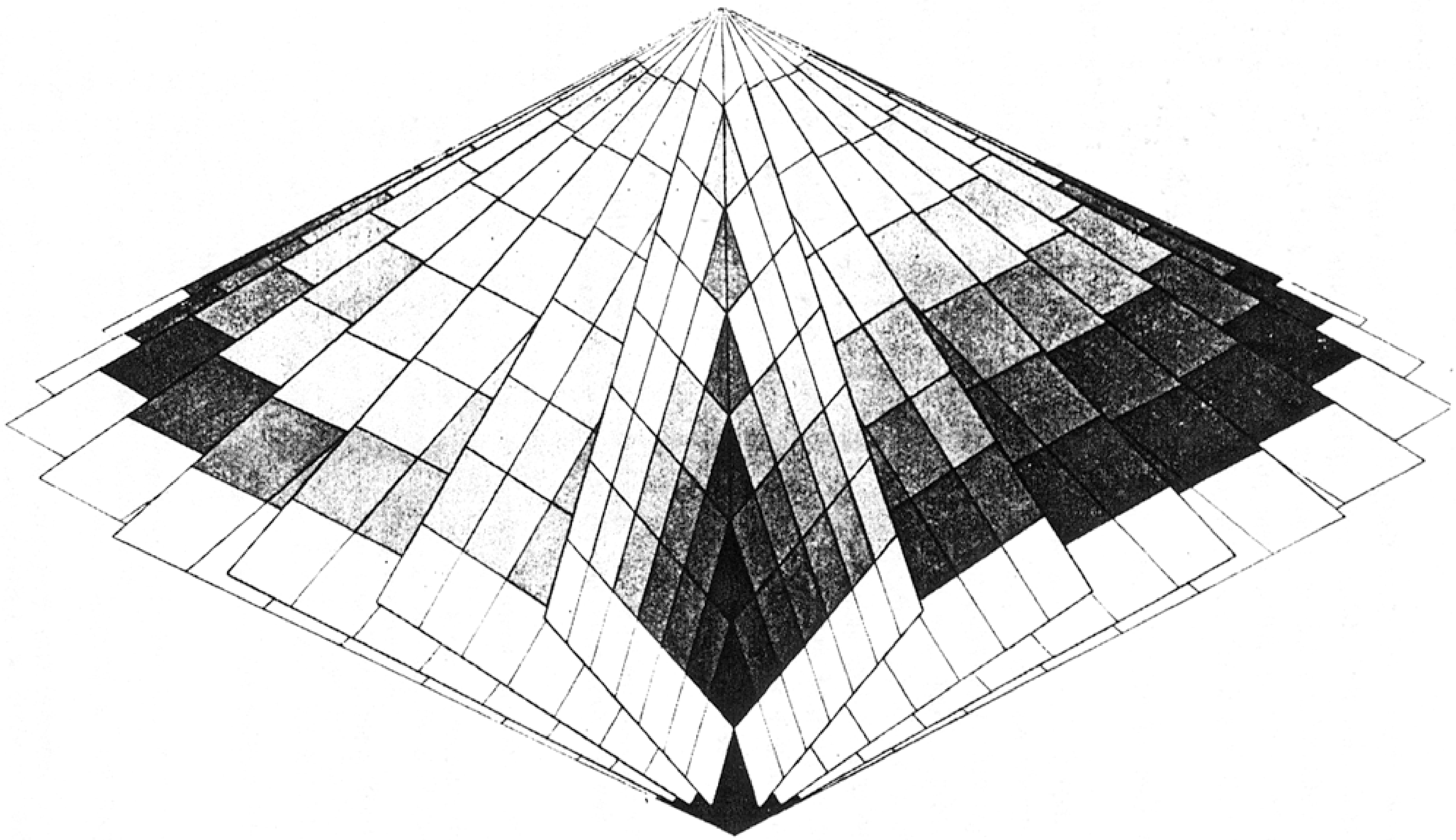


Bild 12. Der Farbkörper.

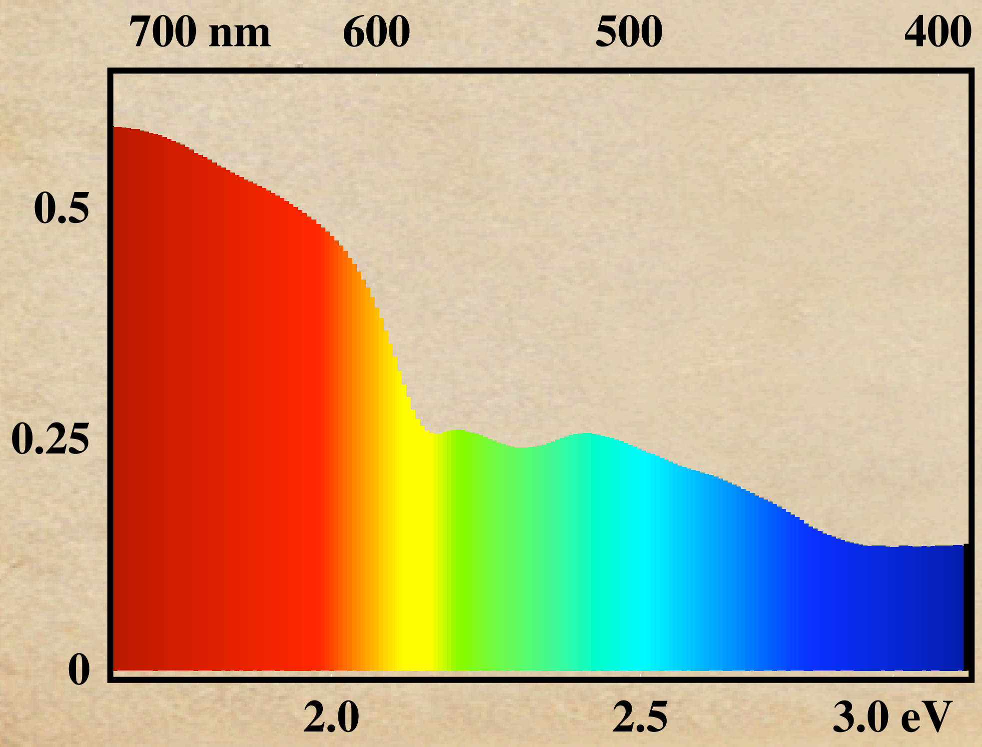
In Ostwald's double cone the pages (full color-white-black triangles) are bound at the gray axis to a "periodic" book (no need for front or back covers).

Although Ostwald used empirical methods to find suitable pigments, his color atlas is firmly founded on colorimetric principles (NOT eye measure!) and can be computed (and shown on the computer screen) from standard colorimetric tables.

It is different in kind from Munsell's system.

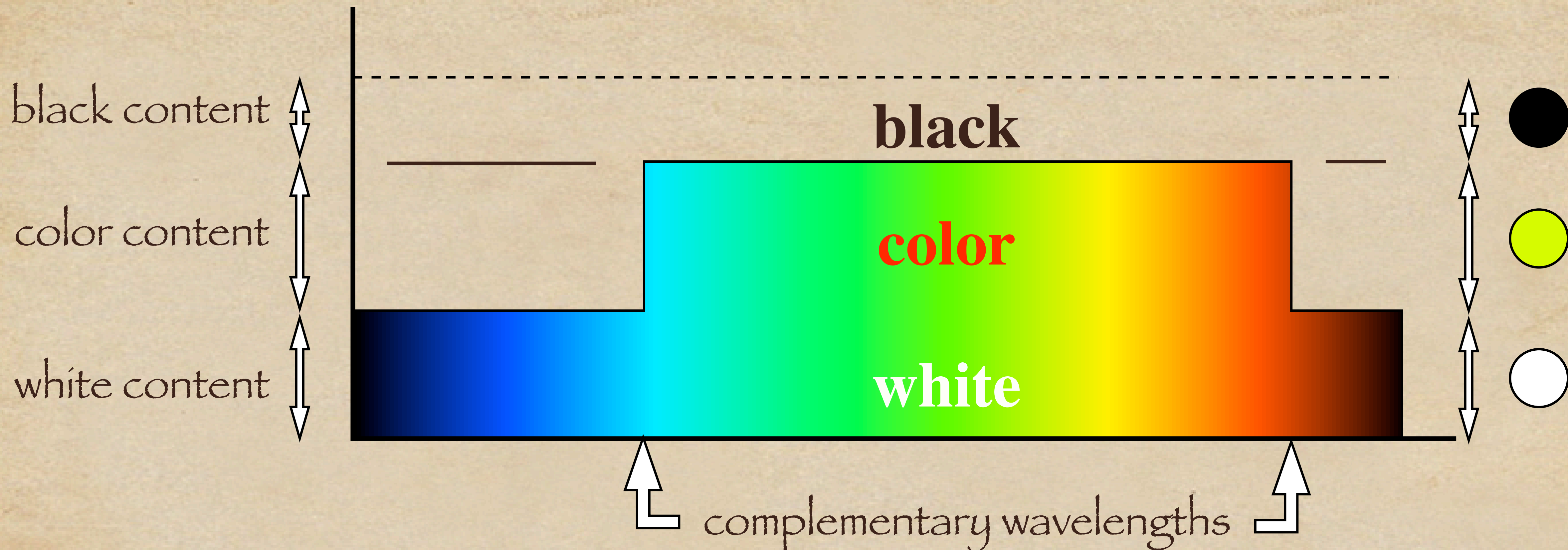
Color
&
Spectral Signature

Reflectance spectra of natural materials (such as skin) can be captured very well through Ostwald's scheme, at least for colorimetric purposes.



Ostwald asked a physicist: “What is the best recipe for yellow paint?” The answer was “zero reflectance thoughout the spectrum except at 580 nm”.
Ostwald noticed that this will produce a BLACK paint!

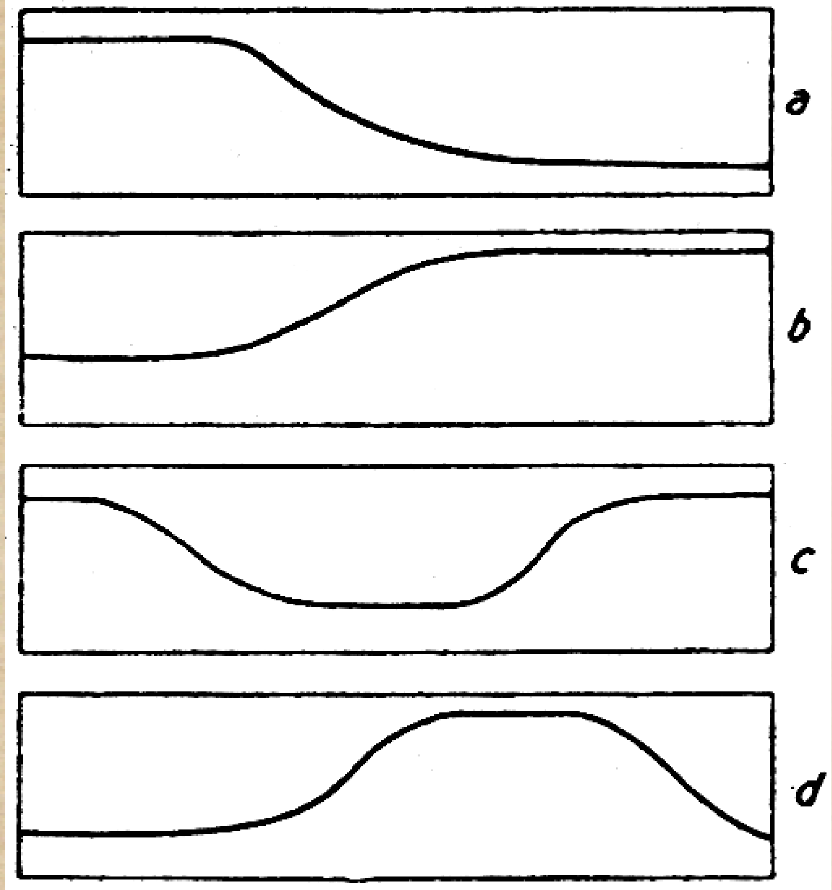
Ostwald looked at spectral reflectance of actual good paints and noticed that yellows reflect half of the spectrum! There are no “monochromatic” object colors.



• Ostwald schematized spectral signatures in terms of partitive mixtures of spectral reflectances: Black, white and a full color. This cuts down the ∞ degrees of freedom to a mere 3! For colorimetric purposes this suffices.

• Ostwald proposed to cut down the spectrophotometry to a determination of full color # and CWK contents.

Actual spectral signatures are not of the ideal Ostwald type (although often not too different). Thus the simple methods pushed by Ostwald will fail to characterize spectral signature completely.



Ostwald was evidently aware of this but failed to stress the point. Although Ostwald's methods are not exact they are often very good approximations and quite useful when applied wisely.

Some conclusions

- Ostwald managed to clear up the relation between the color circle and the spectrum
- Ostwald managed to replace “eye measure” with colorimetric definitions
- Ostwald’s color atlas may have a few flaws, but is a *principled construction,* in contradistinction to Munsell’s mere *eye measure* result
- Ostwald’s “spectroscopy” (when understood rightly!) has many useful applications.

What ever happened to Ostwald's Color Science?

History has not been kind to Ostwald. His major achievements are not acknowledged in the Anglosaxon literature and – when mentioned at all – are misinterpreted. An embarrassment!

For example, Ostwald's color atlas is the only *principled* construction of its kind available today. It is different *in kind* from the Munsell system in that it obviates the need for eye measure (psychology). It is perfectly suited to the computer age. Yet this remains unrecognized, despite the need.

The current industry standard (CIE-Lab) is an awkward mix of colorimetry and arbitrary definitions (loosely based on the Munsell system), full of magical numbers and *ad hoc* functions. Yet, commonly enough, people confuse it with *science*!

Thank you for your attention!

j.j.koenderink@phys.uu.nl