handprint : an artist's color wheel

handprint.com (http://www.handprint.com/HP/WCL/color16.html)

an artist's color wheel

An earlier page described several modern color models (http://www.handprint.com/HP/WCL/color7.html#models), including the latest CIE color difference and color appearance models, and a later page explained how the hue circle from any color model can be used to create an artist's color wheel (http://www.handprint.com/HP/WCL /color13.html#createwheel).

This page presents my own color wheels, the result of considerable study. My understanding of the problems involved has changed over the past several years, so I present both the wheel originally published in 1999, and the version I developed in 2006.

Both wheels show the color appearance locations of all major watercolor pigments (http://www.handprint.com/HP/WCL/waterfs.html) in use today. Both wheels are based on **visual complementary colors**. The wheels differ in their chroma scaling of all colors, and in the spacing and visual complements assigned to blue and violet colors.

Some artists, from force of habit, may prefer a color wheel based on mixing complements. I try to dissuade you from that route, but if you choose it, I provide the you'll need to get started.

Because the visual and mixing location of pigments sometimes differ by a large amount, this page tries to explain . It turns out they are caused by the green reflectance in many paints, and can be summed up in three simple rules.

visual vs. mixing complements

To make a color wheel, we have to tackle the problem first encountered with the secondary color wheel (http://www.handprint.com/HP/WCL/color13.html#secondary): how do we define complementary colors (http://www.handprint.com/HP/WCL/color13.html#compprobs)?

To recap, **complementary colors** are two hues with balanced or opposing color characteristics; that's why they're opposite each other on the color wheel. But the way we define that opposition gives us different results.

In subtractive color mixing (http://www.handprint.com/HP/WCL/color5.html#theorysub), complementary colors are two *dyes, paints or inks* that can be mixed in some proportion to create a gray color. This usually means their reflectance curves combine to make a **metameric color** or visual equivalent of gray, not the flat reflectance curve (http://www.handprint.com/HP/WCL/color3.html#reflectance) of a true neutral. This approach closely ties complementary colors to the problem of mixing paints.

In additive color mixing (http://www.handprint.com/HP/WCL/color5.html#theoryadd), complementary colors are the two monochromatic (single wavelength) *lights* that can be mixed to produce the perception of white light, or the two surface colors whose reflectance curves can be combined (with a color top (http://www.handprint.com/HP/WCL/colortop.html)) to produce the same result. This method closely ties complementary colors to a specific chromaticity diagram (http://www.handprint.com/HP/WCL /color7.html#CIE1976uv) and the problem of mixing lights.

Finally, in color appearance models (http://www.handprint.com/HP/WCL /color7.html#CIECAMab) based on surface colors (painted color samples, rather than colored lights), complementary colors are any two colors at opposite ends of a straight line through the achromatic center of the color model's hue plane (http://www.handprint.com/HP/WCL/color2.html#huespace), or colors on opposite sides (http://www.handprint.com/HP/WCL /color7.html#munsellgeometry) of a perceptually defined hue circle. This approach closely ties complementary colors to the actual visual impact of colors, and to our color psychology.

If we compare the results of subtractive paint mixing, additive light mixing and perceptually defined color models, we find that **visual and mixing complements are almost never the same**. The visual complement of ultramarine blue is a yellowish green, but the mixing complement of ultramarine blue is a dull deep yellow; mixing ultramarine blue and greenish yellow paints produces a dark bluish green. The visual complement of phthalo green is close to quinacridone rose, but the mixing complement of phthalo green is a middle red; mixing phthalo green and quinacridone rose paints gives a muted dark violet, not a neutral tone. And so on. (These color circle comparisons (http://www.handprint.com/HP/WCL/vismixmap.html) clarify the different hue relationships that appear in visual and mixing color circles.)

So we have to choose from among competing approaches when we build a color wheel. The easiest way to review these choices is to compare visual and mixing complements side by side, using the major "cool" pigments as the basis for comparison. (More extensive information is provided in the section on mixing

complementary paints (http://www.handprint.com/HP/WCL
/tech17.html#mixing).) This table is worth careful study!

color theory

(http://www.handprint.com/HP/WCL/wcolor.html)

visual vs. mixing complements

cool key colorwarm visual
complementswarm mixing
complements Indanthrone Blue PB60 (http://www.handprint.com/HP/WCL
/waterb.html#PB60)Hansa Yellow Medium PY97
Benzimida Yellow PY151/154
Cadmium Yellow Pale PY37
Copper Azomethine PY117/129Raw Umber PBr7
Raw Sienna PBr7
Gold Ochre PY43
Benzimida Orange PO62
Hansa Yellow Deep PY65 Ultramarine Violet PV15 (http://www.handprint.com
/HP/WCL/waterv.html#PV15)
[*blue shade*, M. Graham]Quinacridone Deep Gold PO49
Yellow Ochre PY43
Raw Sienna PBr7
Chrome Titanate PBr24
Cadmium Yellow Deep PY35 Ultramarine Blue PB29
(http://www.handprint.com/HP/WCL/waterb.html#PB29)Hansa Yellow Deep
PY65

Nickel Azomethine Yellow PY150

Antrapyrimidine Yellow PY108Raw Umber PBr7

Quinacridone Orange PO48

Benzimida Orange PO62 Cobalt Blue Deep PB72 (http://www.handprint.com/HP/WCL/waterb.html#PB72)Raw Umber PBr7

Raw Sienna

Quinacridone Orange PO48

Benzimida Orange PO62 Cobalt Blue PB28 (http://www.handprint.com/HP/WCL/waterb.html#PB28)Isoindolinone Yellow PY110

Nickel Dioxine Yellow PY153

Cadmium Yellow Deep PY35

Chrome Titanate PBr24

Yellow Ochre PY43

Raw Sienna PBr7

Raw Umber PBr7Raw Umber PBr7

Benzimida Orange PO62 Prussian Blue PB27 (http://www.handprint.com/HP/WCL/waterb.html#PB27)

Phthalo Blue RS PB15:1 (http://www.handprint.com/HP/WCL/waterb.html#PB15)Venetian [Mars] Red PR101

Quinacridone Gold PO48 Phthalo Blue PB15 (http://www.handprint.com/HP/WCL/waterb.html#PB15)Quinacridone Gold PO49

Raw Umber PBr7Venetian [Mars] Red PR101

Cadmium Orange PO20

Perinone Orange PO43 Phthalo Blue GS PB15:3 (http://www.handprint.com/HP/WCL/waterb.html#PB15)Quinacridone Gold PO49

Gold Ochre PY42

Raw Umber PBr7Venetian [Mars] Red PR101

Gold Ochre PY42

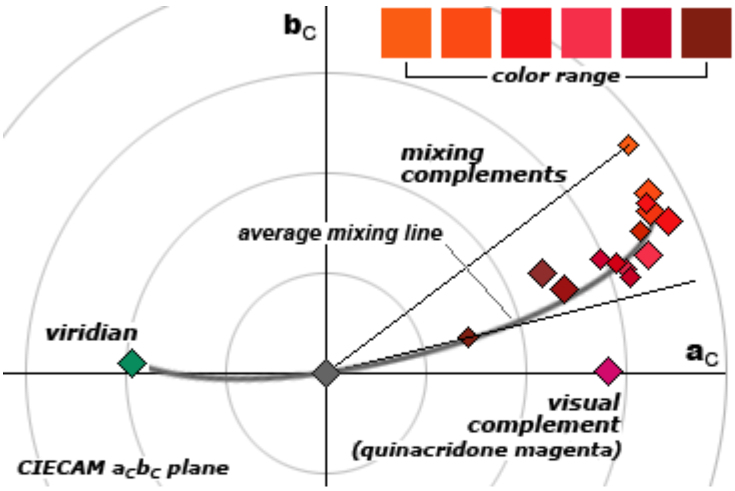
Perinone Orange PO43 Cerulean Blue PB36 (http://www.handprint.com/HP/WCL/waterb.html#PB36)

[*red shade*, M. Graham]Benzimida Orange PO62
Gold Ochre PY42
Burnt Umber PBr7Burnt Sienna PBr7
Burnt Umber PBr7 Manganese Blue PB33 (http://www.handprint.com/HP/WCL/waterb.html#PB33)
Phthalo Cyan PB17 (http://www.handprint.com/HP/WCL/waterb.html#PB17)Cadmium Orange PO20
Burnt Umber PBr7Cadmium Scarlet PR108 Cerulean Blue PB35 (http://www.handprint.com/HP/WCL/waterb.html#PB35)
[*green shade*, Winsor & Newton]Venetian [Mars] Red PR101 Phthalo Turquoise PB16 (http://www.handprint.com/HP/WCL/waterb.html#PB16)Pyrrole Orange PO73
Perinone Orange PO43
Quinacridone Orange PO48
Burnt Sienna PBr7
Burnt Umber PBr7Perinone Orange PO43
Cadmium Scarlet PR108 Cobalt Turquoise PB36 (http://www.handprint.com/HP/WCL/waterb.html#PB36)
Cobalt Teal Blue PG50 (http://www.handprint.com/HP/WCL/waterg.html#PG50)Quinacridone Red PR209
Quinacridone Pyrrolidone PR N/A
Cadmium Red Deep PR108
Perylene Maroon PR179
Indian Red PR101Pyrrole Orange PO73
Pyrrole Scarlet PR255
Quinacridone Maroon PR206
Cadmium Red PR108
Perylene Maroon PR179
Cadmium Red Deep PR108 Phthalo Green BS PG7 (http://www.handprint.com/HP/WCL/waterg.html#PG7)Quinacridone Magenta PR122

Thioindigo Violet PR88Quinacridone Maroon PR206
Perylene Maroon PR179
Pyrrole Scarlet PR255
Pyrrole Red PR254
Cadmium Red PR108 Viridian PG18 (http://www.handprint.com/HP/WCL /waterg.html#PG18)Quinacridone Maroon PR206
Perylene Maroon PR179
Pyrrole Red PR254
Naphthol Scarlet PR188
Naphthol Red PR112
Naphthol Red PR170 Phthalo Green YS PG36 (http://www.handprint.com /HP/WCL/waterg.html#PG36)
*Permanent Green [Deep]*Manganese Violet PV16
Cobalt Violet PV49Quinacridone Rose PV19
Quinacridone Red PV19
Benzimida Maroon PR171 *Hooker's Green*
*Permanent Green [Light]*Manganese Violet PV16Dioxazine Violet PV23/37
Chromium Oxide Green PG17 (http://www.handprint.com/HP/WCL /waterg.html#PG17)
Perylene Black PBk31 (http://www.handprint.com/HP/WCL /waterw.html#PBk31)Cobalt Violet Deep PV14Dioxazine Violet PV23
Cobalt Violet Deep PV14
Ultramarine Violet RS PV15 *Sap Green*
*Phthalo Yellow Green*Dioxazine Violet PV23
Ultramarine Violet RS PV15Dioxazine Violet PV23 *Permanent Green Yellowish Olive Green*
Cadmium Lemon PY35Ultramarine Violet BS PV15
[M. Graham][none] *Note: Mixing complements depend on the pigments used by a specific brand of watercolor paint. The mixing complements listed here may not apply in oil or acrylic mediums.*

Now, there are some artists who claim that mixing complements are the correct or best ones to use in a color wheel; Stephen Quiller (http://www.handprint.com/HP/WCL/book3.html#quiller) even calls them "the true complements." But there are compelling reasons to use visual complements instead.

The basic problem is insurmountable: it is **impossible to define a consistent color wheel using mixing complements**. (See the section on substance uncertainty (http://www.handprint.com/HP/WCL/color5.html#subprobs) for a full explanation.) You can find some glaring examples in the table (above), or see the fuzzy relationship among all major watercolor pigments in my mixing complement diagram (http://www.handprint.com/HP/WCL/tech17.html#mixchart). This makes the hue relationship among mixing complements downright incomprehensible by itself, as **both hue and chroma affect the mixing complement relationship**.



visual & mixing complements of viridian

As one example, the *visual complement* of the beautifully granulating, blue green viridian (PG18 (http://www.handprint.com/HP/WCL/waterg.html#PG18)) is quinacridone magenta (PR122 (http://www.handprint.com/HP/WCL/waterc.html#PR122)). But the many mixing complements (http://www.handprint.com/HP/WCL/mixtable.html#PG18) of viridian range in color from red brown (benzimida maroon, PR171 (http://www.handprint.com/HP/WCL/waterc.html#PR171)), to maroon (perylene maroon, PR179 (http://www.handprint.com/HP/WCL/waterr.html#PR179)), to carmine (anthraquinone red, PR177 (http://www.handprint.com/HP/WCL/waterc.html#PR177)), to deep red (naphthol red deep, PR170 (http://www.handprint.com/HP/WCL/waterr.html#PR170)), to light middle red (quinacridone red, PR209 (http://www.handprint.com/HP/WCL/waterr.html#PR209)), to dark middle red (pyrrole red, PR254 (http://www.handprint.com/HP/WCL/waterr.html#PR254)), to scarlet (naphthol scarlet, PR188 (http://www.handprint.com/HP/WCL/waterr.html#PR188)), to red orange (pyrrole orange, PO73 (http://www.handprint.com/HP/WCL/watero.html#PO73)). Notice that these mixing complments become more saturated, they shift toward a yellower hue. They clearly do not define the same color, or even the same hue; and several of these paints, such as perylene maroon, are mixing complements of turquoise (blue green) paints as well.

But don't take my word for it. Joy Turner Luke (http://www.handprint.com/HP/WCL/book3.html#luke), in her notes to the *New Munsell Student Color Set,* writes that:

It is impossible to create a subtractive color wheel where every color combined with the color opposite it on the wheel will mix to gray. This type of color wheel, which is found in many books for artists, (1) can only be approximate; (2) applies only to complex subtractive mixture, not to color vision; and (3) precludes understanding many other things about color.

Impossible to create? I present ample evidence to support that claim in the section on mixing complementary paints (http://www.handprint.com/HP/WCL/tech17.html#mixing). It is not possible to create a color wheel to summarize *subtractive* mixing complement relationships because any single paint can be the mixing complement of several different paints on the opposite side of the wheel, and because two paints of the same color can have completely different mixing complements. For this reason, I present the same information as a list of watercolor mixing complements (http://www.handprint.com/HP/WCL /mixtable.html).

However the key issue raised by Luke is her second point: **a mixing color wheel has little to do with color vision**. There is nothing contradictory or impossible about a *visual* color wheel: each hue is the complement of a single other hue, and no other. What's more, the **visual color wheel shows us the end, not the means, of artistic design**. It guides our painting decisions by showing us how to *effectively combine the colors we see,* not how to mix gray colors from commonly used paints.

Think about it: the viewer of your painting has no idea how you created a specific color. Was that gray mixed with two paints, or twenty? Were the paints orange and blue, or red and turquoise, or violet and green? The *color assembly decisions* in paintings disappear, or leave traces that are too complex to interpret. So why would you base your color design on the mixing relationships no viewer can see?

In contrast, the *visual* color relationships are inherent in the way we see color, and they define natural contrast effects such as complementary colored shadows (http://www.handprint.com/HP/WCL/color10.html#shadows). They are always right on the surface, in the immediate visual impact of the painting, no matter how the paints that made the colors were mixed. To control that impact, **painters should understand and use the visual complementary colors**.

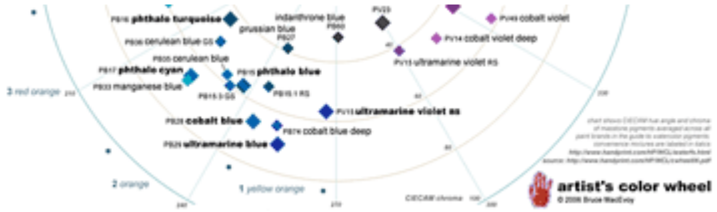
The mixing color wheel, at best, shows an artist how to mix gray colors if he hasn't figured that out already and, as we've seen, it can't even do that very well. The visual color wheel shows us the true color harmonies, the color harmonies of the eye and mind, and so unlocks the *visual* esthetic impact of *any* color image in *every* color medium.

the artist's color wheel

With those points in mind, I set out to make a *visual color wheel* adapted specifically to the needs of painters and graphic artists, and drawing on as many reliable sources as I could find. I think this is one of the best color wheels you will find for making both visual design and paint mixing decisions.

It is useless to talk about color in the abstract, because artists must deal with specific colorants made of specific pigments. So my **artist's color wheel** represents the masstone color locations of the 90 most commonly used watercolor pigments, rather than color categories ("red orange") or clusters of similar pigments.

Paint Measurement. Spectrolino measures reflectance from 380nm to 730nm in 10nm intervals, using a diffraction grating with 45°/0° viewing geometry, 10° observer, and a neutral filter over a tungsten (A) light source in the apparatus. It yields the standard XYZ tristimulus values, which were used in the CIECAM color appearance model (http://www.handprint.com/HP/WCL/color7.html#CIECAM) with a standard graphics illuminant (D50) to plot the color locations on the CIECAM $\mathbf{a_C b_C}$ plane. I used my own spectrophotometric measurements of single pigment watercolor paints and convenience mixtures.



(http://www.handprint.com/HP/WCL/cwheel06.html)

click here (http://www.handprint.com/HP/WCL/cwheel06.html) for a full size view in a new window

click here (http://www.handprint.com/HP/WCL/cwheel06.pdf) for a printer friendly (Adobe Acrobat PDF) version of the artist's color wheel (330K)

To print the color wheel, set page orientation
to "landscape" and print to fit an 8.5" x 11" sheet of paper.

Here are the main design features of the artist's color wheel:

The pigment markers show the hue and chroma of pigments as measured in single pigment paints (http://www.handprint.com/HP/WCL/pigmt6.html#painttypes) and *averaged across all brands* reported in the guide to watercolor pigments (http://www.handprint.com/HP/WCL/waterfs.html). Pigments are indicated by generic name and color index name; convenience mixtures of two or more pigments are labeled in italics without color index names.

Hues directly opposite each other (that can be connected by a line drawn through the center of the wheel) are **visual complementary colors** as defined by the pigment locations on the CIECAM a_Cb_C plane (http://www.handprint.com/HP/WCL/camwheel.html). (Note that the CIECAM locations are reversed left to right, to make the color circle consistent with Munsell and most artist's color wheels.)

The twelve spokes of the tertiary color wheel (http://www.handprint.com/HP/WCL/color13.html#tertiary) are inserted to guide your eye in finding complements on opposite sides of the wheel. (They do not represent equal hue spacing in CIECAM or Munsell.)

The masstone chroma (http://www.handprint.com/HP/WCL/pigmt8.html#chroma) of paints is approximately indicated by the distance of pigment markers from the center of the wheel. (Pigments farther from the center are more intense or saturated.)

Straight mixing lines between any two paint markers can be used to estimate the *approximate* saturation costs (http://www.handprint.com/HP/WCL/color14.html#satcost) of the paint mixtures. Note that it is not possible to create a color wheel where all mixing lines are straight, and this problem can't be fixed (http://www.handprint.com/HP/WCL/tech34.html#mixfix) by shifting the location of hues around the color circle.

The artist's color wheel cannot accurately show mixing complementary colors, because of the problems described above with subtractive color mixing. However, subtractive mixing complements are exhaustively listed in the page on mixing complements (http://www.handprint.com/HP/WCL/mixtable.html), and approximate mixing complement relationships are noted around the violet to green circumference of the color wheel.

The hue angle distance between two colors in the artist's color wheel approximates the perceived difference between colors of the same lightness or value, and corresponds fairly closely to the spacing of hues in the Munsell Color System (http://www.handprint.com/HP/WCL/color7.html#MUNSELL).

Despite the care taken to make this artist's color wheel as accurate as possible, the word *approximate* is important to keep in mind when using it to judge paint mixing problems. The lightness of a paint or color mixture can significantly affect the chroma or mixing behavior. Any subtractive color wheel is fundamentally a poor predictor of paint mixing (http://www.handprint.com/HP/WCL/color5.html#subprobs) results, and as we've just seen, can fix it. Treat the wheel as a starting point for your own color judgments with the brands of paints you prefer to use.

tour of the color wheel

I found that the most effective way to learn the color wheel was to work through all the major color categories around the circumference, sampling one or more paints at each of the major points, and mixing these paints in all possible combinations. This approach is described in the page on paint wheels (http://www.handprint.com/HP/WCL/tech15.html).

If you know the **hue, lightness and chroma** of any paint, you will have a pretty good idea of how that paint will mix with other paints. So part of the basic knowledge of any painter is knowing the location of the major pigments in relation to the twelve major points of the color wheel. Let's take the tour.

1 : LIGHT YELLOW (primary) : This hue is a tangy, bright yellow, the color of lemons and canaries, which often takes on a distinct greenish appearance, especially at darker values. For most viewers it matches a monospectral hue (http://www.handprint.com/HP/WCL/color18.html#huegeometry) of around 575nm. The visual color wheel locates hansa yellow light (PY3 (http://www.handprint.com/HP/WCL/watery.html#PY3)), cadmium lemon (PY35 (http://www.handprint.com/HP/WCL/watery.html#PY35)) and the benzimidazolone yellows (PY151 (http://www.handprint.com/HP/WCL/watery.html#PY151), PY154 (http://www.handprint.com/HP/WCL

/watery.html#PY154), or PY175 (http://www.handprint.com/HP/WCL/watery.html#PY175)) at the "primary" yellow point. Artists differ in how much green they prefer in this hue; the Munsell color circle picks a very lemony yellow as the exemplar. My own preference is for **hansa yellow** (PY97 (http://www.handprint.com/HP/WCL/watery.html#PY97)) because it is very lightfast, intense, and has a hue that contains (to my eye) no hint of orange or green. The historical pigment aureolin (PY40 (http://www.handprint.com/HP/WCL/watery.html#PY40), not shown because it is impermanent) is a slightly cooler and less intense yellow, while bismuth yellow (PY184 (http://www.handprint.com/HP/WCL/watery.html#PY184)) is whiter and therefore less intense than the usual cadmium lemon. Copper azomethine or green gold (PY117 (http://www.handprint.com/HP/WCL/waterg.html#PY117)) and nickel titanate (PY53 (http://www.handprint.com/HP/WCL/watery.html#PY53)) are relatively dull light yellows and therefore less suitable as a primary mixing paint; all have a distinct green or greenish gray color. All yellows at this color point quickly lose their characteristic yellow appearance as they are darkened or made less intense, turning rapidly into a dull warm green and then into a peculiarly lifeless gray. Note that none of these yellows can be used in neutralizing mixtures with blue violet; they all make dull greens.

2 : DEEP YELLOW (tertiary) : This is the golden color of highway caution signs, school buses and autumn squash. It corresponds to a monospectral hue (http://www.handprint.com/HP/WCL/color18.html#huegeometry) at around 595nm. The visual wheel places hansa yellow deep (PY65 (http://www.handprint.com/HP/WCL/watery.html#PY65)), cadmium yellow deep (PY35 (http://www.handprint.com/HP/WCL/watery.html#PY35)) and nickel dioxine yellow (PY153 (http://www.handprint.com/HP/WCL/watery.html#PY153)) at this location, but many cadmium paints labeled yellow orange or yellow medium are also close to this hue. (The Munsell Book of Color chooses a color slightly warmer than cadmium yellow deep for this hue location.)

A less intense but very lovely alternative is quinacridone deep gold (PO49 (http://www.handprint.com/HP/WCL/watere.html#PO49)). This second hue point is interesting for several reasons. Mixing the hue from yellow and red produces a duller mixture than expected, often duller than a red orange mixed from the same paints. This is also the yellowest hue that can neutralize mixtures with blue violet; mixing complements (http://www.handprint.com/HP/WCL/mixtable.html) for cool colors really start at this hue point and continue through purple. Finally, this is the hue point at which the yellowest earth pigments (http://www.handprint.com/HP/WCL/earthp.html) are located the many "yellow" iron oxide pigments (PY42 (http://www.handprint.com/HP/WCL/watere.html#PY42) or PY43 (http://www.handprint.com/HP/WCL/watere.html#PY43), marketed as raw sienna, yellow ochre, mars yellow or gold ochre). If this hue is made even less intense, it turns into a grayish or grayish brown hue, typical of raw umber (PBr7 (http://www.handprint.com/HP/WCL/watere.html#PBr7)). A handy way to remember the yellow range of the spectrum is to remember that most "medium" cadmium yellows are about half the distance from cadmium yellow deep to hansa yellow light, and hansa yellow medium (PY97 (http://www.handprint.com/HP/WCL/watery.html#PY97)) is about half the distance from cadmium medium to hansa yellow light.

3 : RED ORANGE (secondary) : This is an especially intense and powerful hue, just at the boundary between scarlet and orange (hues on either side of this hue point). It corresponds to a monospectral hue (http://www.handprint.com/HP/WCL/color18.html#huegeometry) at around 630nm. The best exemplars of this color are pyrrole orange (PO73 (http://www.handprint.com/HP/WCL/watero.html#PO73))or the slightly warmer cadmium scarlet (PR108 (http://www.handprint.com/HP/WCL/waterr.html#PR108)) or cadmium red orange (PR108 (http://www.handprint.com/HP/WCL/watero.html#PR108)). The less intense pigments in this color category include the "red" iron oxide pigments (including venetian red, indian red and light red, all PR101 (http://www.handprint.com/HP/WCL/watere.html#PR101)) and the synthetic organic equivalent quinacridone maroon (PR206 (http://www.handprint.com/HP/WCL/watere.html#PR206); Daniel Smith's quinacridone burnt scarlet and Winsor & Newton's brown madder). It's also important to familiarize yourself with the pigments that fall between the deep yellow and red orange color points: cadmium orange (PO20 (http://www.handprint.com/HP/WCL/watero.html#PO20)) and benzimidazolone orange (PO62 (http://www.handprint.com/HP/WCL/watero.html#PO62)) are the most intense, while among the duller but very useful paints are quinacridone gold (PO48 (http://www.handprint.com/HP/WCL/watere.html#PO48)) and the extremely useful burnt sienna (PBr7 (http://www.handprint.com/HP/WCL/watere.html#PBr7)), a moderately dull, orange iron oxide pigment that is a mixing keystone in the "warm" color range. Even darker and less intense is burnt umber (PBr7 (http://www.handprint.com/HP/WCL/watere.html#PBr7)), which can be used in place of burnt sienna in any mixture that you want to take to a darker and duller color (although it is oddly ineffective at mixing true grays with most blue paints). Naphthol scarlet (PR188 (http://www.handprint.com/HP/WCL/waterr.html#PR188)) and pyrrole scarlet (PR255 (http://www.handprint.com/HP/WCL/waterr.html#PR255)) are very intense pigments on the red side of this color point. It's interesting that artists tend to have a distinctive preference in warm paints: some (Caravaggio, Turner, Gauguin, Matisse) seem to like red orange focal hues, while others (Van Gogh, Rubens, Rembrandt) seem to prefer a deep yellow.

4 : MIDDLE RED (tertiary) : This is close to a "pure" red that leans neither toward orange nor violet. Its closest monochromatic counterpart is extraspectral, matched with a mixture of 90% extreme "red" wavelengths (around 700nm) and about 10% violet light (http://www.handprint.com/HP/WCL/color18.html#huegeometry). The visual color wheel places quinacridone magenta (PR122 (http://www.handprint.com/HP/WCL/waterc.html#PR122)) or quinacridone violet (PV19 (http://www.handprint.com/HP/WCL/waterc.html#PV19B)) at this location. (It's remarkable that the entire color span from middle red to red violet, formerly represented by a shoddy gang of fugitive organic pigments, has been handsomely replaced by different shades of a single modern and lightfast pigment: quinacridone (http://www.handprint.com/HP/WCL/pigmt1d.html#quinacridone).) Notice that cadmium red medium (PR108 (http://www.handprint.com/HP/WCL/waterr.html#PR108)) or pyrrole red (PR254 (http://www.handprint.com/HP/WCL/waterr.html#PR254)) correspond to the average conception of unique red or a pure "red" spectral hue, and that the range from scarlet to deep red is visually quite small about the same as the distance between the yellow and green shades of phthalo green. And there is quite a crowd of "warm red" pigment alternatives between the red orange and middle red points on the wheel. These include the cadmium reds (PR108 (http://www.handprint.com/HP/WCL/waterr.html#PR108)), naphthol reds (PR112 (http://www.handprint.com/HP/WCL/waterr.html#PR112) and PR170 (http://www.handprint.com/HP/WCL/waterr.html#PR170)), quinacridone reds (PR209 (http://www.handprint.com/HP/WCL/waterr.html#PR209) and PV19 (http://www.handprint.com/HP/WCL/waterc.html#PV19R)), perylene scarlet (PR149 (http://www.handprint.com/HP/WCL/waterr.html#PR149)), perylene red (PR178 (http://www.handprint.com/HP/WCL/waterr.html#PR178)), perylene maroon (PR179 (http://www.handprint.com/HP/WCL/waterr.html#PR179)). Notice that in the visual color wheel the red and yellow spans of the spectrum are approximately the same size: deep yellow is the middle boundary between the two. Most of these reds mix strong blacks with phthalo green BS (PG7 (http://www.handprint.com/HP/WCL/waterg.html#PG7)), and strong dark grays with cobalt turquoise or teal blue. I find it useful to divide the warm colors in two groups the paints that can or cannot mix a green color with a greenish blue paint such as phthalo cyan or phthalo blue GS. Yellows up to cadmium yellow deep can, and reds down to benzimidazolone orange cannot.

5 : MAGENTA (primary) : This is a distinctive bright, bluish red hue that is easy to recognize once you've seen it. It corresponds to the hue that J.W. von Goethe (http://www.handprint.com/HP/WCL/book3.html#goethe) called *purpur,* a term that is mistranslated as "red" or "bright red" in the English edition of his *Farbenlehre*. It has no monospectral counterpart, but must obtained by mixing roughly equal parts of "red" and "blue violet" wavelengths. Unfortunately pigments with this hue are darker and/or less saturated than the spectral light mixture, giving paints at this locating a relatively purplish or pale color. An excellent choice for this point is cobalt violet (PV49 (http://www.handprint.com/HP/WCL/waterv.html#PV49)); the only other pigment alterative is manganese (mineral) violet (PV16 (http://www.handprint.com/HP/WCL/waterv.html#PV16)), though it is too blue and too dull to make useful mixtures with the warm pigments. (I don't consider the hues from quinacridone magenta to ultramarine blue, and the complements from phthalo green YS to cadmium lemon, to be either warm or cool.) Some "accomplished" artists continue to use the fugitive magenta and carmine pigments, including alizarin crimson and rose madder genuine. But apparently they do so with a furtive conscience (http://www.handprint.com/HP/WCL/pigmt6.html#responsibility): posing as an interested buyer, I've found that a few don't notify their collectors of the lightfastness issues related to their choice of paints.

6 : PURPLE (tertiary) : A relatively rare hue encountered most often in certain flowers or gems. It has no spectral counterpart, but is obtained by mixing "violet" (400nm) wavelengths with a very small amount of "red" light. This location is represented by either dioxazine violet (PV23 (http://www.handprint.com/HP/WCL/waterv.html#PV23)), the red shade of ultramarine violet (PV15 (http://www.handprint.com/HP/WCL/waterv.html#PV15)), or cobalt violet deep (PV14 (http://www.handprint.com/HP/WCL/waterv.html#PV14)). Few artists use these mineral purple pigments because they have poor tinting strength, are not especially bright, and are strongly granulating; many avoid dioxazine violet because it tends to fade in some watercolor paint brands. To avoid these problems many paint brands offer the color as a purple convenience mixture (http://www.handprint.com/HP/WCL/waterv.html#purples) of a rose or magenta quinacridone and ultramarine blue. Points 5 through 7 of the wheel are also confusing to learn because the apparent hue of a paint depends on its lightness and/or chroma: magenta paints appear to redden with increased chroma, and blue violet paints appear to shift toward purple. This is especially noticeable in quinacridone violet (PV19 (http://www.handprint.com/HP/WCL/waterc.html#PV19B)), which has the same spectrophotometric hue as quinacridone magenta (PR122 (http://www.handprint.com/HP/WCL/waterc.html#PR122)), but appears distinctly bluer because the color is darker and less intense. A similar hue difference appears between indanthrone blue (PB60 (http://www.handprint.com/HP/WCL/waterb.html#PB60)) and ultramarine blue (PB29 (http://www.handprint.com/HP/WCL/waterb.html#PB29)).

7 : BLUE VIOLET (secondary) : Here we enter the blue hues, corresponding to a monospectral hue (http://www.handprint.com/HP/WCL/color18.html#huegeometry) at around 440nm. The "blue" shade of ultramarine violet (PV15 (http://www.handprint.com/HP/WCL/waterv.html#PV15)) and the mystically dark indanthrone blue (PB60 (http://www.handprint.com/HP/WCL/waterb.html#PB60)) are the best pigment representatives for this hue and the visual complements for "primary" yellows at point 1. The very popular pigment ultramarine blue (PB29 (http://www.handprint.com/HP/WCL/waterb.html#PB29)) is placed between points 7 and 8, where it is the visual complement of a middle yellow to deep yellow hue). The nearness of ultramarine blue to a violet color is revealed by the fact that the blue shade of ultramarine violet (PV15 (http://www.handprint.com/HP/WCL/waterv.html#PV15)) is very close by.

8 : MIDDLE BLUE (tertiary) : This point approximately corresponds to the average conception of "unique" blue or "pure" blue. It corresponds to a monospectral hue (http://www.handprint.com/HP/WCL/color18.html#huegeometry) at around 465nm. The few pigment exemplars at this point include cobalt blue (PB28 (http://www.handprint.com/HP/WCL/waterb.html#PB28)), phthalo blue (PB15 (http://www.handprint.com/HP/WCL/waterb.html#PB15)) and iron [prussian] blue (PB27 (http://www.handprint.com/HP/WCL/waterb.html#PB27)). The visual wheel also locates the warm shades of cerulean blue (PB35 (http://www.handprint.com/HP/WCL/waterb.html#PB35)) or the green shade of phthalo blue (PB15:3 (http://www.handprint.com/HP/WCL/waterb.html#PB15)) approximately at this color point. Pay special attention to brand variations in color when selecting paints around points 8 and 9 on the color wheel. Mixing complements for the blues at point 8 are typically deep yellow and middle orange, and their dull "earth" equivalents such as raw sienna or gold ochre.

9 : CYAN (primary) : This is a bright, light greenish blue, also unmistakable once learned, representing the "primary" cyan in paint mixing. It corresponds to a monospectral hue (http://www.handprint.com/HP/WCL/color18.html#huegeometry) at around 480nm, which is close to the wavelength of maximum transmission (and therefore the color) of water ice (though most landscape water contains suspended matter that shifts the color toward green or brown). For this hue there is one good pigment choice phthalo turquoise (PB16 (http://www.handprint.com/HP/WCL/waterb.html#PB16)) although a very green phthalo blue (PB15:3 (http://www.handprint.com/HP/WCL/waterb.html#PB15)) or the discontinued phthalo cyan (PB17 (http://www.handprint.com/HP/WCL/waterb.html#PB17)) also serve well, in paints and in printing inks. Manganese blue (PB33 (http://www.handprint.com/HP/WCL/waterb.html#PB33)) is more granular but also a good hue substitute, as are cobalt turquoise or the greener shades of cerulean blue (PB36 (http://www.handprint.com/HP/WCL/waterb.html#PB36)) and cobalt teal blue (PG50 (http://www.handprint.com/HP/WCL/waterg.html#PG50)). The mixing complements for all these paints are typically a red orange or scarlet hue, especially in the dull "earth" colors.

10 : BLUE GREEN (tertiary) : This hue is a lovely dark green with just a hint of blue, and corresponds to a monospectral hue (http://www.handprint.com/HP/WCL/color18.html#huegeometry) at around 495nm. The visual color wheel places the dark and intense phthalo green blue shade (PG7 (http://www.handprint.com/HP/WCL/waterg.html#PG7)) and the lighter and less saturated viridian (PG18 (http://www.handprint.com/HP/WCL/waterg.html#PG18)) and cobalt titanate blue shade (PG50 (http://www.handprint.com/HP/WCL/waterg.html#PG50)) at this location. The mixing complements for this point are usually middle or deep red, and the fact that red and blue green are such antagonistic colors in color vision (lying at opposite ends of the r/g opponent contrast) means that many of these neutral mixtures are especially dark and rich.

11 : GREEN (secondary) : This green corresponds to a monospectral hue (http://www.handprint.com/HP/WCL/color18.html#huegeometry) at around 515nm. The visual color wheel puts phthalo green yellow shade (PG36 (http://www.handprint.com/HP/WCL/waterg.html#PG36)) and the much duller and more opaque chromium oxide green (PG17 (http://www.handprint.com/HP/WCL/waterg.html#PG17)) close to this point. Winsor & Newton used to market a yellow version of cobalt titanate green (now discontinued, PG50 (http://www.handprint.com/HP/WCL/waterg.html#PG50)) at this hue. All the rest of green paints at this and the next point are convenience greens (http://www.handprint.com/HP/WCL/waterg.html#convenience) that vary widely in transparency, saturation and lightfastness. (The pros and cons of these and other green pigments are dished up in the page on mixing green (http://www.handprint.com/HP/WCL/tech34.html#pigments).)

12 : YELLOW GREEN (tertiary) : To close out the color wheel, there is a long slog of green and more green until we come back to cadmium lemon. This yellow green corresponds to a monospectral hue (http://www.handprint.com/HP/WCL

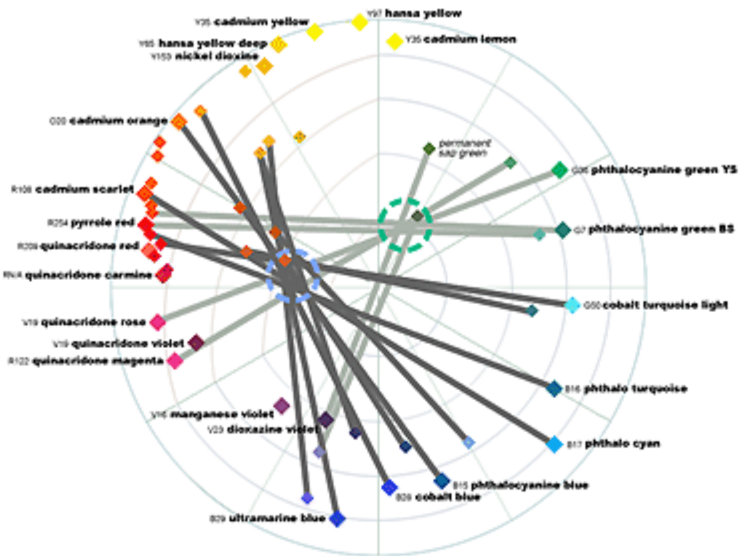
/color18.html#huegeometry) at around 555nm which is the chromaticity of our peak daylight sensitivity (http://www.handprint.com/HP/WCL /color1.html#psf). Despite its sun bright character, yellow green is an unpopular color in everything from clothing to cars to home decor, and there are no pigments available to provide it: the vivid greens, leaf greens and yellow greens marketed in this hue are all convenience mixtures (http://www.handprint.com /HP/WCL/waterg.html#convenience) of phthalo green (usually PG36) and a bright yellow. I find sap green (listed as a convenience mixture under PG36 (http://www.handprint.com/HP/WCL/waterg.html#PG36)) is more convenient to use, and it is also an excellent mixing and visual complement for dioxazine violet. Note that the perceptual difference indicated the visual color wheel between phthalocyanine green PG7 and cadmium lemon is almost exactly the same as that between quinacridone magenta and ultramarine violet. And the mixing complements for all these yellow green colors are the purple colors directly opposite on the visual color wheel.

At first reading, this survey of the color wheel seems to cover a confusingly large number of pigments and colors. The differences between scarlet and brown, or yellow and ochre paints what I call the unsaturated color zones (http://www.handprint.com/HP/WCL/color12.html#unzones) also complicate color judgments on the "warm" side of the color wheel.

But the simple exercise of mixing paint wheels (http://www.handprint.com /HP/WCL/tech15.html) is an effective way to learn these color variations and the major color differences that result from mixtures of paints from any two color points. And you will find that painting experience will gradually clarify and strengthen your grasp of the color wheel, and with it your confidence at navigating the complexities of color space.

why the difference?

Why does this difference between mixing and visual complementaries occur? When we look at the differences in the mixing and visual pairs around the wheel, we discover a pattern of systematic bias. To make this bias clearer, draw lines connecting the blue and green pigments with their *mixing complements* on the warm side of the wheel.



mixing lines between blue and green pigments and their mixing complementary "warm" pigments

Nothing is precise in subtractive color mixing, yet it's obvious the lines from the blue pigments (from the blue shade of ultramarine violet PV15 (http://www.handprint.com/HP/WCL/waterv.html#PV15) to cobalt teal blue PG50 (http://www.handprint.com/HP/WCL/waterg.html#PG50)) all converge on a small area of the wheel located roughly around the pigment red iron oxide (venetian red, PR101 (http://www.handprint.com/HP/WCL/watere.html#PR101)). This is indicated by the blue circle.

In contrast, the mixing lines for the few green pigments and convenience mixtures all pass through a small area located near chromium oxide green (PG17 (http://www.handprint.com/HP/WCL/waterg.html#PG17)), indicated by the green circle.

The reason for these differences is not hard to find, if we consider the reflectance curves of the different paints and the differences between additive and subtractive color mixing.

All the "green mixing" warm pigments (that is, the light yellow (http://www.handprint.com/HP/WCL/IMG/RC/yellow.html) to yellow orange (http://www.handprint.com/HP/WCL/IMG/RC/rcPO62.jpg) paints that will mix a green color with a blue paint) contain significant amounts of **green" reflectance** even though visually they seem to contain no green color. As the paint hue shifts from yellow toward red, this "green" reflectance diminishes, but does not completely disappear until the hue is around a scarlet red (http://www.handprint.com/HP/WCL/IMG/RC/rcPR188.jpg).

These "green" reflecting warm pigments are *visual* complements to paints from cobalt blue to phthalo cyan (http://www.handprint.com/HP/WCL/IMG/RC/blue.html), and these colors also contain a significant amount of "green" reflectance, even though they appear primarily blue. This "green" reflectance increases as the paint color shifts toward blue green, which compensates for the loss of "green" reflectance as their visual complements shift from yellow to scarlet.

When these blues are mixed with their visual complements, there is enough "green" reflectance common to *both* paints that the mixtures appear as various dull greens rather than neutral grays.

To remedy this problem and get a true gray, we must neutralize this excess "green" reflectance. We do this by adding the complement of green, magenta. It's exactly as if we mixed the visual complement paints phthalo cyan and benzimidazolone orange, got a dull green color, and realized we needed to add a little magenta paint to neutralize this green toward gray.

So here's the trick: we could also **mix the magenta and orange first**, which would result in the same gray when mixed with phthalo cyan. But the magenta and orange mixture would itself be close to the pyrrole red that is the *mixing* complement of phthalo cyan. The difference in hue between the visual and mixing complements represents this added "red" or "magenta" reflectance, and is the reason why the convergence point for the mixing lines is shifted away from the center of the wheel toward a magenta hue.

For the green to blue green (http://www.handprint.com/HP/WCL/IMG/RC/green.html) paints that are visual complements to blue violet, purple or red violet colors, the problem arises from an excess of **red" and "blue violet" reflectance** that magentas and red violets (http://www.handprint.com/HP/WCL/IMG/RC/magenta.html) all have in common. In these cases mixing the visual complements gives a dull blue violet color. Now we have to choose a mixing complement to neutralize this "purple" reflectance, and yellow green will do that nicely. It's as if we mixed the visual complements, for example phthalo green BS and quinacridone magenta, got a dark violet as a result, and had to add a little yellow green paint to the mixture to neutralize it back to gray.

This comparison of visual and mixing wheels leaves us with these **three rules for mixing complements**:

(1) You can ignore the yellow paints from cadmium lemon up to hansa yellow deep; they are not effective mixing complements with any cool pigment.

(2) All blues, from ultramarine violet BS to cobalt teal blue, form mixing complements with paints from hansa yellow deep to middle red, indicated by lines converging on the blue circle. In general, dull (low chroma) warm pigments,

such as quinacridone maroon or raw umber, are more effective neutralizing paints than very intense pigments.

(3) All greens, from phthalo green BS to sap green, form mixing complements with paints from deep red to violet, indicated by lines passing through the green circle; the yellow greens can all be neutralized with dioxazine violet.

The simplest way to remember the mixing complementary relationships in the paints you use is just to memorize the best neutralizing pigment for each blue or green pigment from the table of mixing complements (http://www.handprint.com/HP/WCL/mixtable.html). The blue and green circles can help you to find the most likely mixing complements for any cool mixture, if you can identify the location of the mixture on the artist's color wheel (or the existing blue paint it most resembles).

making your own color wheel

With this "complete color wheel," and the explanation of how other artists have made their own color wheels (http://www.handprint.com/HP/WCL/color13.html#createwheel), you can easily make color wheels of your own.

When you do this, you will keep the information about colors or paints that is necessary to solve a specific artistic problem (identifying mixing complements; identifying paints that mix well together), and throw away the rest.

Your personal color wheel start with the actual selection of paints in your palette. You won't include as many pigments as the scientific or generalist color wheels I've described on this and the previous page.

Any artist can make their own color wheel by following these five steps:

1. Decide on the colors (few or many, and specific hues) that will be in the palette this is the overall palette design (http://www.handprint.com/HP/WCL/paletfs.html).

2. Choose a paint for each hue with the chroma and lightness most appropriate for the total color effect the palette should achieve. (The choice of tonal values determines the relative lightness (http://www.handprint.com/HP/WCL/color11.html#valchrom) of all mixed colors and the value range (http://www.handprint.com/HP/WCL/vwheel.html) of the palette as a whole.)

3. Choose either as the basic color geometry that the wheel will represent.

4. Position the paints around the color wheel according to their hue or color mixing behavior.

5. Determine the additional information about the paints (if any) to represent by the concentric placement of the paints inside the wheel. (In Quiller's wheel, this extra information is chroma and lightness; in Kosvanec's wheel, it is paint transparency and staining.)

An artist can bring other considerations to designing a color wheel than the ones I've shown (the texture of the paints, or their behavior when they are rewetted or charged with clear water).

By now you should realize that there is no "objective" color wheel, no "best" color palette. There are many color wheels and palettes, each one suited to a particular artist or artistic purpose. By working through the steps just described, you can make your own color wheel.

Art means you do it whatever way makes sense for you. One of the pleasureful puzzles of painting is the process of continually rediscovering your personal color wheel, rather than memorizing somebody else's "perfect" color system.

(http://www.handprint.com/HP/WCL/wcolor.html)