handprint : color wheels

handprint.com (http://www.handprint.com/HP/WCL/color13.html)

color wheels

A **color wheel** is a schematic hue circle (http://www.handprint.com/HP/WCL/color2.html#huecircle) that artists use to guide color mixing and color design decisions.

Isaac Newton's hue circle (http://www.handprint.com/HP/WCL/color2.html#newtoncircle) was intended to explain light mixtures only, and did not contain primary colors as artists think of them today. Eighteenth century "color theorists" substituted paint mixtures for light mixtures and replaced factual color relationships with simplified, symmetrical and idealized color theory icons (http://www.handprint.com/HP/WCL/color18.html#geometry). This distorted Newton's concept (http://www.handprint.com/HP/WCL/color6.html#confusions) of the hue circle and misrepresents subtractive color mixing (http://www.handprint.com/HP/WCL/color5.html#theorysub).

This point regarding the primary system is rarely made clear enough. Primary colors are colors that appear to mix in the mind, in the same way that primary tastes can mix on the palate: we experience them as mutually present in the mixture in the way that blue and yellow make green, or magenta and yellow make orange, or magenta and blue make violet, or black and white make gray. Whether or not they behave in the same way in mixtures only illuminates the difference between physical reality (paints) and the mind (color perceptions), or the difference between additive and subtractive color mixing.

In additive mixing, the colors that cannot mix together in this purely conceptual way, such as a green and a violet, produce white, or the absence of color. So we don't experience a color in any situation that appears violet and green at the same time unless it is in iridescence, or the color of lilies on the stem. Yelow and magenta can however be thought of together, as the color orange, or the appearance of a red disk viewed through a yellow medium. In subtractive mixing, a green and violet mixture results in a neutral gray or dark substance that is lacking more in luminance than in hue. White mixture is the mixture of color attributes, black is the mixture of physical reflectances. (You cannot mix a "white" paint.)

The major discrepancies between our conceptual and the material facts of color appear as major differences in the color mixtures. The mixture of blue and yellow light makes white, but the same mixture in paints makes green. All these differences become apparent in the differences between the visual mixing of white and the material mixing of dark gray the curved mixtures of mixing complementary colors (http://www.handprint.com/HP/WCL/mixtable.html).

A color wheel can either represent the additive or subtractive behavior of color. The additive mixtures can be arranged to be perfectly conceptual and geometrical, while the subtractive mixtures must be based on material colors, which are unevenly distributed in the color space (many more saturated than unsaturated, many more in the "warm" than the "cool" hue range, and so on) and mix in way that produces curved mixing lines in the conceptual color space.

This page explains how artists' color wheels:

promote a rigid conception of

adopt an of complementary colors

distort the actual between paints

disguise the dependence of the on paint selection

ignore the complications created by substance uncertainty (http://www.handprint.com/HP/WCL/color5.html#subprobs) that occur in all paint mixtures.

We'll also discover that for effective color mixing; it's often unnecessary color wheel are often unnecessary. This makes it clear that **the color wheel is not a color theory** it's just a crude way to anticipate the often complex or confusing results of mixing artists' pigments. Experienced artists learn to use the color wheel as a compass to color improvisation (http://www.handprint.com/HP/WCL/color14.html#mixmethod).

The page concludes with a basic guide to color naming and common watercolor paint names.

creating a color wheel

Artist's color wheels represent the color mixing characteristics of paints as markers around a circle. This is a radical simplification of paint attributes. Before we get into color wheels, it is useful to see how this simplification is done.

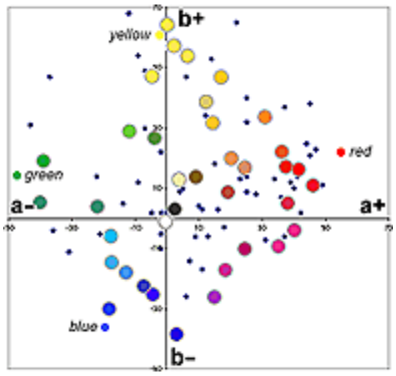
The first step in making a color wheel is to locate paint colors in a color space (such as CIELAB (http://www.handprint.com/HP/WCL/color7.html#CIELAB)), which is done by spectrophotometric measurements of standard paint samples. (The earliest color wheels were created by judging a paint's hue by eye; this produced less reliable hue circles.)

color theory

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

In any modern color model (http://www.handprint.com/HP/WCL/color7.html#hsv), a paint's hue and chroma can be represented on a two dimensional **hue/chroma plane**. In CIELAB this plane is defined by the **a*** and **b*** dimensions. The diagram (right) shows the location of 37 frequently used watercolor paints as small colored circles; other less popular paints are indicated by small dots. (The positions of the four unique hues (http://www.handprint.com/HP/WCL/color2.html#heringtheory) are indicated in italics.) This a*b* plane (http://www.handprint.com/HP/WCL/labwheel.html) represents the hue (http://www.handprint.com/HP/WCL/color3.html#colormakinghue) of a paint as the proportion of red (**a**+), green (**a-**), yellow (**b**+) or blue (**b-**) in the color. Thus, orange is a combination of red (**a**+) and yellow (**b**+), so orange appears in the upper right (**a**+/**b**+) part of the **a*b*** plane.

The distance of a color from the center (where the **a*** and **b*** dimensions cross) indicates the chroma (http://www.handprint.com/HP/WCL/color3.html#colormakingchroma) of the paint. A paint that is dull or gray has low chroma and is close to the center, while paints that are bright or intense have high chroma and are near the edges of the diagram. Note the significant imbalance of chroma across hues: most of the highest chroma (http://www.handprint.com/HP/WCL/color12.html#huesat) paints are in the **a**+**b**+ (yellow to red) part of the plane, while the least intense paints are opposite these, in the **ab** blues.

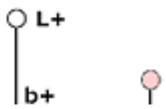


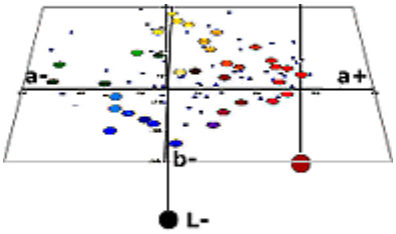
the a*b* color plane

position of the four unique hues shown in italics; red in CIELAB conventionally shown on the right

Unfortunately, black and white are placed together at the center of the **a*b*** plane, even though they are opposite colors. This is because we're missing the third dimension, the **L*** or lightness (http://www.handprint.com/HP/WCL/color3.html#colormakingvalue) dimension, that separates light colors from dark. If we view the **a*b*** plane from the side (diagram, right), or examine the artists' value wheel (http://www.handprint.com/HP/WCL/vwheel.html), we can see how much important information (http://www.handprint.com/HP/WCL/color11.html#dominance) is lost. Yet it is common in conventional artist's color wheels to **ignore lightness differences** among paints.

Worse, many color wheels **ignore chroma differences** among paints as well burnt sienna and cadmium scarlet would both be considered the same *red orange*. When that is done, we also discard the location of the colors as near or far from the neutral center. Then what's left? Only the **hue angle** of the paint, which (in CIELAB) is the angle of the paint's location measured in counterclockwise direction from the **a**+ dimension.

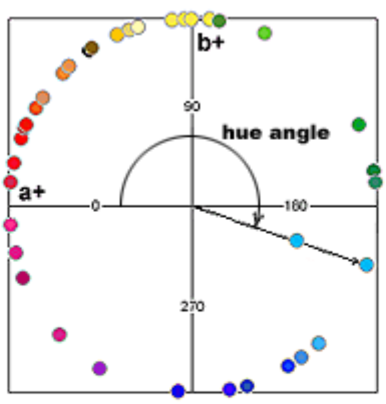




the a*b* plane viewed
from the side

And thus we have the traditional method for creating an artist's color wheel: define hue by drawing a line from the origin of the **a*b*** plane (where the two dimensions cross) through the location of the paint. This line defines the hue angle in relation to the **a*** and **b*** dimensions. Then simply push the paint location away from the origin along this line until it is located on the circumference of a circle. Do this for every paint color you want to represent, and you have the template for an artist's color wheel (diagram, right).

The hue circle rests on a "pure" conception of hue, an abstraction, because "red" is not light or dark, or intense or dull, it's simply the hue "red" separate from any of the other visual attributes that characterize a sunset, a brick, or a drop of blood. So we have thrown away quite a lot of the information about paints we started with. In particular, the hue circle mingles colors of different chroma or lightness. This is problematic in warm colors, where dull and intense reds, and light or dark yellows, produce very different color mixtures.



a hue circle with hue angle

(red is now shown on the left to match conventional color wheels)

Some artists address these problems by removing dull or dark valued colors entirely, leaving only intense colors along the circumference; or by creating concentric hue circles, with the duller or darker colors grouped in rings closer to the center. But these are somewhat arbitrary ways to put back into the color wheel the information that was already thrown away.

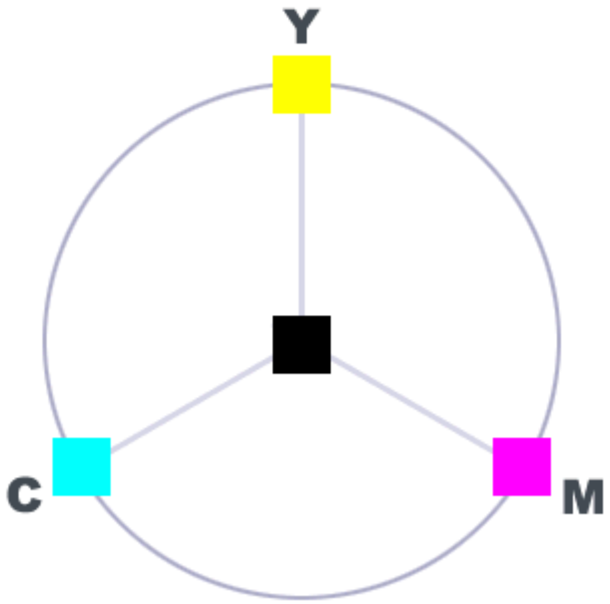
A few "color theorists" don't stop here. The paint locations in CIELAB (or most other color models) do not correspond exactly to geometrical symmetry and the principles of primary color mixing. So the hue circle location of paints is tidied up a bit by moving the color markers around until they fit into a triangle (diagram, right). The NCS color model (http://www.handprint.com/HP/WCL/color7.html#NCS) shifts the markers around until the four unique hues are at the ends of the horizontal and vertical dimensions. Some color wheels adjust the location of paints around the hue circle so that certain hues fall neatly on evenly spaced "spokes". In each case, the color locations are manipulated to **represent a color theory**. At this point the artist is no longer throwing away information he's creating symbolism.

primary color wheel

The backbone of the traditional painter's color wheel is the subtractive **primary triad**. Primary colors have been part of the professional lore of painters and dyers since at least the 17th century.

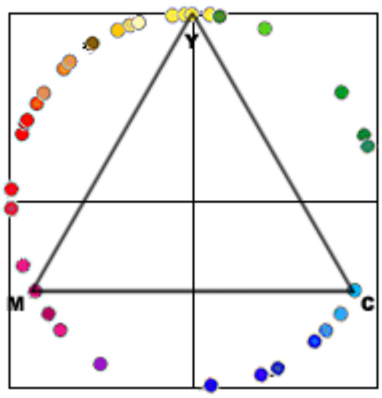
The diagram shows a simple color wheel divided into three equal sections by three primary colors. At the center of the wheel, the black square symbolizes the dark neutral color that results from mixing all three subtractive "primaries" together: this is a color wheel for paints, not for light.

The **geometrical symbolism of the color wheel is a pervasive feature of traditional color theory**. Paints are shown as ideal colors, not real substances, and the mixture relationships between them are shown as balanced, symmetrical and harmonious. This symbolizes esthetic purity and intellectual control, but it also badly misrepresents the of paints.



the primary (three hue) color wheel

Primary Colors and Paints. This bare bones color wheel comprises **three primary colors: magenta (M), light yellow (Y), and cyan (C)**. By convention (since the late 19th century), light yellow is always placed at the top of the wheel (at "12 o'clock"); magenta is inconsistently placed, depending on the source, either on the left (at "8 o'clock") or on the right (at "4 o'clock") with cyan opposite. (To minimize confusion, on this site I've adopted the Swedish NCS (http://www.handprint.com/HP/WCL/color7.html#NCS), OSA UCS (http://www.handprint.com/HP/WCL/color7.html#OSA-UCS), CIELAB (http://www.handprint.com/HP/WCL/color7.html#CIELAB) and CIECAM (http://www.handprint.com/HP/WCL/color7.html#CIECAM) conventions of placing "red on right".) Thanks to modern intense and lightfast pigments, we can choose much more effective paints than were available to artists of the past, and as a result **the traditional primary triad red, yellow, and blue is obsolete** and should not be taught.



tidying up the hue circle

Before reading further, you may want to experiment with your own primary triad palette (http://www.handprint.com/HP/WCL/palette4c.html) to experience for yourself the gamut or range of colors it can mix. (This is also a great way to familiarize yourself with the basic mixing behavior of watercolors.) I suggest the following paints (click on the color index name (http://www.handprint.com/HP/WCL/pigmt6.html#label) to identify the paint marketing names (http://www.handprint.com/HP/WCL/pigmt6.html#colors) for the pigment used by different manufacturers):

primary light yellow : benzimidazolone yellow (PY151 (http://www.handprint.com/HP/WCL/watery.html#PY151) or PY154 (http://www.handprint.com/HP/WCL/watery.html#PY154)) or hansa yellow medium (PY97 (http://www.handprint.com/HP/WCL/watery.html#PY97))

primary magenta : quinacridone magenta (PR122 (http://www.handprint.com/HP/WCL/waterc.html#PR122)) or quinacridone rose ("permanent rose", PV19 (http://www.handprint.com/HP/WCL/waterc.html#PV19R))
primary cyan : phthalocyanine blue GS (PB15:3 (http://www.handprint.com/HP/WCL/waterb.html#PB15)) or phthalocyanine cyan (PB17 (http://www.handprint.com/HP/WCL/waterb.html#PB17)).

It's worth the trouble to explore what happens if you use different pigments for each of these primary colors, using the explained below. These substitutions introduce you to the substance uncertainty (http://www.handprint.com/HP/WCL/color5.html#subprobs) that comes with the choice of specific paints, and help you understand why some primary paints are better than others for a minimal (three paint) palette.

For example, the quinacridone magenta can be swapped for quinacridone violet (PV19 (http://www.handprint.com/HP/WCL/waterc.html#PV19B)), quinacridone red (PR209 (http://www.handprint.com/HP/WCL/waterr.html#PR209)), or anthraquinone red (PR177 (http://www.handprint.com/HP/WCL/waterr.html#PR177)). (Don't bother with alizarin crimson [PR83 (http://www.handprint.com/HP/WCL/waterr.html#PR83)] or genuine rose madder [NR9 (http://www.handprint.com/HP/WCL/waterc.html#NR9)], as these are too fugitive for professional art; I also feel quinacridone carmine [PR N/A (http://www.handprint.com/HP/WCL/waterr.html#PR%20N/A)] has borderline lightfastness, especially if used in tints.) These different pigments will create distinctive reds, oranges and deep yellows when mixed with a single medium or light (lemon) yellow paint.

The phthalo cyan color can be replaced with cerulean blue GS (PB36 (http://www.handprint.com/HP/WCL/waterb.html#PB36)), cerulean blue (PB35 (http://www.handprint.com/HP/WCL/waterb.html#PB35)), phthalocyanine turquoise (PB16 (http://www.handprint.com/HP/WCL

/waterb.html#PB16)), or even cobalt blue (PB28 (http://www.handprint.com/HP/WCL/waterb.html#PB28)). These choices produce dramatic changes in the quality of mixed purples and greens.

The alternatives for the primary yellow color are especially numerous. I prefer hansa yellow because it a very intense, pure yellow pigment, neither warm nor cool, but it is only marginally lightfast so I recommend benzimida yellow instead. Some artists prefer a warmer yellow such as a cadmium yellow medium (PY35 (http://www.handprint.com/HP/WCL/watery.html#PY35)) or the splendid nickel azomethine yellow (PY150 (http://www.handprint.com/HP/WCL/watery.html#PY150)), while others like a cooler, "light" or lemon yellow such as bismuth yellow PY184 (http://www.handprint.com/HP/WCL/watery.html#PY184), benzimida lemon PY175 (http://www.handprint.com/HP/WCL/watery.html#PY175), hansa yellow light PY3 (http://www.handprint.com/HP/WCL/watery.html#PY3), or cadmium lemon yellow PY35 (http://www.handprint.com/HP/WCL/watery.html#PY35)). Artists such as Trevor Chamberlain (http://www.handprint.com/HP/WCL/palette4h.html) prefer a dull deep (orangish) yellow, such as yellow ochre PY43 (http://www.handprint.com/HP/WCL/watere.html#PY43) or raw sienna PBr7 (http://www.handprint.com/HP/WCL/watere.html#RS), to create subdued orange and green mixtures.

Why Use Primary Colors? These many alternative paint selections highlight the fundamentally **arbitrary nature of primary colors**. You can choose a wide range of paints for a palette: there is nothing fundamental about one paint as opposed to any other. In fact, artists have for many centuries used palettes that contain no primary colors at all (http://www.handprint.com/HP/WCL/palette4b.html). (For more on how artists choose paints for their palettes, see this page (http://www.handprint.com/HP/WCL/intstud.html).)

So why do artists choose primary colors over any others? Because it is traditional to do so. The three 18th century justifications for the use of three primary paint colors were: (1) the paints can **mix every hue in the hue circle** (we cannot do this with just two paints, no matter which two we choose), (2) each primary paint cannot be matched by any mixture of the other two primary paints, and (3) the three paints together can mix a perfect neutral or dark gray. (In fact, if criterion 1 is met then criterion 3 is also always satisfied, but this was not clear to artists in the 18th century.)

The commonly stated modern reason for using magenta, yellow and cyan primary paints is more accurate: the primary triad is used (for example, in printing) because it can mix every hue (http://www.handprint.com/HP/WCL/color6.html#modprimary) *at the highest possible chroma,* given the restriction that you must use no more than three paints or inks, and given the selection of cost effective and lightfast pigments available. That is, we simply evaluate the inputs (paint selection) in terms of the outputs (the range of colors the paints can mix). The selection is always in relation to cost effective, available colorants, not in comparison to imaginary ("primary") colors. Thus, because they lacked anything better, 18th and 19th century painters used as a primary red several historical pigments that no artist nowadays would accept for that role.

Why do we focus on chroma (http://www.handprint.com/HP/WCL/color3.html#colormakingchroma)? Because a primary triad of *high chroma* paints has the **largest gamut** in comparison to any other selection of three paints. As explained below, the of a palette is the total possible range of color mixtures that the palette can make, including the complete range of shades, tones and tints (http://www.handprint.com/HP/WCL/color11.html#stt) for every hue. However, variations in the lightness and chroma of a color are created by *diluting* the pigments with water (to reveal the whiteness of the paper) and/or with a black or dark neutral (http://www.handprint.com/HP/WCL/waterw.html#PBk6) paint. Water and a dark neutral paint produce the same *lightness range* in any watercolor palette, but when mixed with the primary paints they substantially dull the saturated colors. Therefore most effective way to increase a palette's gamut is not to expand the lightness range but to increase the chroma of the palette primary paints. For this reason it is convenient to **focus exclusively on the hue and chroma** of undiluted mixtures between two primary paints as a way to define the limits of a palette gamut and to compare the gamuts of different palettes or different versions of the color wheel.

A second reason the primary triad has been so popular is that any color within the gamut can be analyzed into a simple color recipe (http://www.handprint.com/HP/WCL/color6.html#mayer) or proportional mixture of the three colors, plus black paint and/or water or white paint:

color = **% Cyan** + **% Yellow** + **% Magenta** + **% Black** + **% White (Water)**

or, in imitation of the NCS color formula (http://www.handprint.com/HP/WCL/color7.html#colorformula),

color = $\mathbf{\%C(p_1+p_2+p_3) + \%K + \%W}$

where the percentages or proportions of $\mathbf{p_1}$, $\mathbf{p_2}$ and $\mathbf{p_3}$ always add up to 100 or 1, and this mixture is then combined as the proportion of color (**%C**) mixed with black (**%K**) and white (**%W**).

These or similar formulas are especially useful in the printing industry, which relies on standardized primary inks, color mixture recipes (such as the Pantone system), and halftone screens of different densities to mix colored inks in the desired proportions. When the emphasis is on mixture recipes, the primary triad palette is usually represented as an equilateral color mixing triangle (http://www.handprint.com/HP/WCL/color6.html#sloan) rather than a circle, but this has been carried into color wheels as an equal spacing of the three primary colors.

The third and last reason the primary triad palette has been used is because a limited palette creates an **effective or desirable harmony of mixed colors**, adding a distinctive tone or light (http://www.handprint.com/HP/WCL/palette4c.html) to the finished painting. As we have seen in the example of Trevor Chamberlain, painters who follow this strategy do not choose intense paints for their "primaries", in order to get instead a cohesive, lyrical, more atmospheric or natural range of color mixtures. These artists are usually less concerned with color theory than with the paints' handling attributes transparency, staining, pigment texture, tinting strength and lightfastness.

Other reasons are sometimes given in traditional color theory texts for treating primary colored paints as more important than other paints. These either derive from the 18th century color dogmas, as described on another page (http://www.handprint.com/HP/WCL/color6.html#leblon), or they come down from early 20th color theorists such as Johannes Itten and Wassily Kandinsky (http://www.handprint.com/HP/WCL/artist29.html), who attributed spiritual or "moral" qualities to various colors, including the primary colors. However, statements such as *"you can't mix a 'primary' from other colors"* or *"the 'primaries' are fundamental to color vision" or "the 'primary' colors are the primary colors of the universe"* are either misleading generalizations or crackpot nonsense.

Only **three criteria large gamut, analytical mixing recipes and desirable color harmonies** justify the choice of paints for a primary palette.

Mixing Step Scales. At this point it will be extremely useful for you to compare the actual primary triad gamut with the full range of colors possible in watercolor paints. (This is an essential exercise in learning color through paints (http://www.handprint.com/HP/WCL/intstud.html).)

To do this, make a **mixing step scale** between each primary pair of paints you have chosen to use. Mixtures of two primary paints define the chroma limits or brightest colors within the palette's mixing range; any mixture of three "primaries" will be somewhere inside the gamut, duller or closer to gray.

Then compare your mixed colors to the most intense pure pigment paints of similar color. This comparison will show you how well the primary colors reproduce the entire range of colors, and how much their mixtures suffer from saturation costs (http://www.handprint.com/HP/WCL/color14.html#satcost) the reduced color intensity (http://www.handprint.com/HP/WCL/color3.html#colormakingchroma) that results from mixing paints that are far apart on the color wheel.

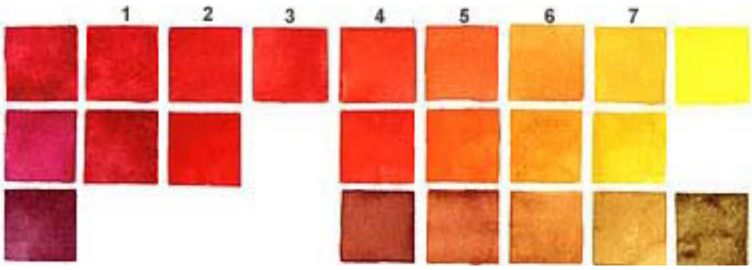
To make the mixing step scale, first mix up a generous quantity of the two primary paints you want to test. Paint each test color on a watercolor paper as a 1" square of color, separated by 8" of blank paper (this allows seven 1" mixing steps between the two colors, separated by 1/8").

With your clean brush, draw off a *very generous amount* of each primary color and mix the two together until you get a hue that appears to you exactly *equally different* from both paints; add one or the other color until you get this right. Paint this mixture as a 1" square in the middle position 4.

With your brush, draw off *roughly half* of this mixture into a new mixing area, and add more of the righthand primary paint until the new mixture appears equally different from the primary and the middle mixture; paint this as a square in position 6. Again, draw off some of this mixture and add the righthand primary a third time to obtain a new hue, halfway between colors 6 and 8, and paint it in square 7. Take what remains of mixture 6 and add the lefthand primary paint until this mixture appears to be exactly between mixtures 4 and 6; apply this as square 5. Then finish squares 1 to 3 in the same way, starting with what remains of mixture 4, to mix color 2.

Don't worry if the dried colors appear different from the hues you thought you had mixed. This happens because of drying shifts (http://www.handprint.com/HP/WCL/cds.html) in the color appearance of the paints. Record this shift by drawing an arrow above the square showing the direction of the hue shift (toward one or the other primary paint); this will help you learn how mixed colors change as they dry.

Finally, paint below each mixed square any alternative paints of the same hue that you want to use for color comparisons. Your finished test page will look similar to the illustration below.



mixing step scale between quinacridone rose and benzimidazolone yellow

Alternative pure pigments (middle row, left to right): quinacridone magenta, quinacridone carmine, pyrrole red, cadmium scarlet, cadmium orange, nickel dioxine yellow, cadmium yellow; (bottom row): quinacridone violet, venetian red, burnt sienna, gold ochre, yellow ochre, raw umber

The illustration shows mixing steps for the rose to yellow mixtures on the warm side of the color wheel. The middle row shows the most intense alternative single pigment paints for each mixed hue; for comparison, the bottom row shows the major earth pigments (with dark quinacridone violet at far left).

Many artists are surprised to discover that these **mixed warm colors are almost as intense as pure pigment paints**. This supports the choice of primary magenta and yellow for a palette, and suggests that pure pigment colors between rose and light yellow may actually be convenience paints they do not significantly add chroma to hues on the warm side of the color wheel, and are included only to provide a specific warm hue without mixing.

As it turns out, most other yellow and magenta/rose paints *will* produce substantially duller mixtures, especially in the orange to deep yellow hues (as we'll). As small differences in chroma are very noticeable on the warm side of the color wheel, and single pigment colors are useful as readymade mixing complements to the cool colors (blues and greens), few artists would do without their customary selection of paints on the warm side of the color wheel.

mixing step scale between phthalo blue GS and quinacridone rose

Alternative pure pigments (bottom row, left to right): tint of phthalo blue GS, cobalt blue, ultramarine blue, dioxazine violet, quinacridone violet

The mixing steps from phthalo blue GS to quinacridone rose present a very different picture. Here the alternative pure pigment paints (bottom row) provide a superior color alternative to each of the mixed hues a difference that is especially striking around ultramarine blue. (Note the obvious: ultramarine blue literally "cannot be mixed from other colors," but it is not a primary blue!)

The pure pigments clearly have a higher chroma (are more intense), in some cases by as much as 50%. So the magenta and cyan paints are inadequate to get the full range colors through this side of the color wheel: pure blue and violet paints would be necessary to extend the intensity of color mixtures.

mixing step scale between phthalo blue GS and benzimidazolone yellow

Alternative pure pigments (bottom row, left to right): tint of phthalo blue GS, cobalt turquoise, phthalo green BS, phthalo green YS

The mixing steps for the greens give similar results: even the dull cobalt turquoise is a more intense color than the equivalent blue green mixture of the "primaries" cyan and light yellow. The blue green and green side of the color wheel could also be augmented with brighter paints to produce more intense color mixtures.

These simple mixing step scales have demonstrated the high cost of using a primary triad palette.

True Primary Color Relationships. We've found that the primary triad produces lopsided mixing results for different hues around the hue circle: bright orange and scarlet mixtures, relatively dull green and blue green mixtures, and very dull purple and blue violet mixtures. Because saturation costs are greater for paints that are farther apart on the hue circle, these mixing studies imply that light yellow and magenta should be closer together in a color wheel than cyan is to either.

actual mixing distance between primary colors spacing matches the maximum saturation cost (dullness) of primary mixtures

The diagram shows how the primary colors should be spaced in a color wheel if we wanted the distance between them to represent accurately the maximum saturation cost (http://www.handprint.com/HP/WCL/color14.html#satcost) (dullness) of their mixtures. (Surprisingly, a nearly identical spacing of primary red, yellow and blue was proposed in a color wheel by Louis Bertrand Castel, in his *L'Optique des Couleurs* of 1740, but his insight was discarded in favor of geometrical simplification.) Obviously, the traditional, equally spaced color wheel **misrepresents the actual mixing relationships among the primary paints**.

Would choosing a different primary blue or primary magenta produce more balanced mixtures? Well, yes and no.

Yes, if the blue or magenta paints were significantly more intense (saturated) than the ones available to us today. Because there is no artists' pigment more intense than a phthalocyanine for the cyan hue or a quinacridone for the magenta hue, we don't have that choice. The most intense yellow, orange, red and rose paints are all lighter valued and have a significantly higher chroma (http://www.handprint.com/HP/WCL/camwheel.html) than currently available green, turquoise, blue or purple paints (with the exception of ultramarine blue, PB29 (http://www.handprint.com/HP/WCL/waterb.html#PB29)), so the pigment choices are imbalanced to begin with.

No, because we are forced to place the magenta and light yellow paints closer together, in order to keep their mixtures highly saturated, because the "warm" hues from red through yellow seem to change hue at lower saturation red and orange become brown, yellow turns into dull green or gray in what I call the unsaturated color zones (http://www.handprint.com/HP/WCL/color12.html#unzones). Choosing a blue that is closer to violet doesn't solve our problems, either: shifting the cyan toward magenta would improve the intensity of blue violet mixtures, but would make the green mixtures duller than they already are.

All these problems are symptoms of the fact that three primary colors cannot mix all visible colors (http://www.handprint.com/HP/WCL/color6.html#imaginary), no matter which three "primaries" or paints we use. The only way around these limitations is to add more colors to the palette.

secondary color wheel

Once we've chosen our three primary or fundamental colors, then color theory introduces a second step: derive three new colors as **mixtures of any two primary colors** in equal proportions at equal tinting strength. In the primary triad :

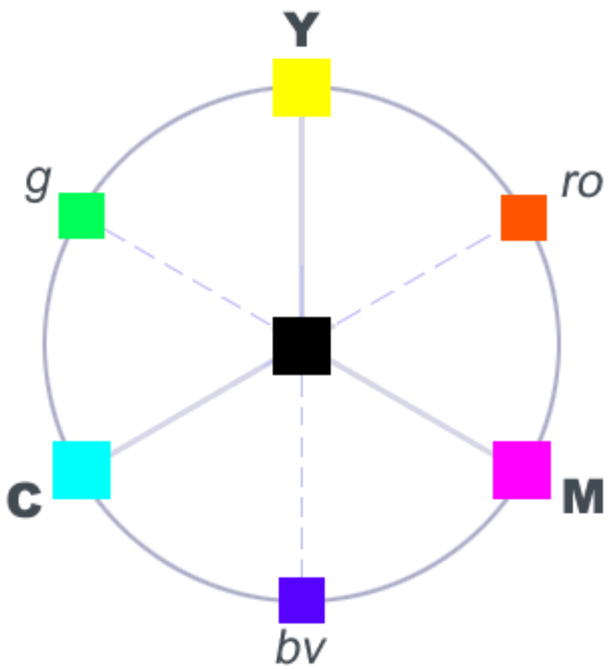
orange =50%M + 50%Y + 0%C violet =0%M + 50%Y + 50%C green =50%M + 0%Y + 50%C

These are the *secondary colors* of the color wheel.

Unfortunately, as we've already seen, these "secondary" mixtures will be the *dullest mixtures* that any two "primaries" will produce, because they are **halfway between two primary colors** and therefore suffer the greatest saturation costs (http://www.handprint.com/HP/WCL/color14.html#satcost).

If dull mixtures don't make us happy, then our only remedy is to **replace the dullest primary color mixtures with new paints**. As we've just seen, there is certainly justification for adding a green paint, to brighten up the dull mixed greens, which would give us the artist's primaries palette (http://www.handprint.com/HP/WCL/palette4d.html) suggested by Leonardo da Vinci. A blue violet paint would also boost color chroma in mixed purples and maroons. So we may as well replace all three secondary mixtures with the most intense paints of similar hues. These become our new secondary colors, and join with the primary paints to make a six paint secondary palette (http://www.handprint.com/HP/WCL/palette4e.html).

Notice that our focus is on the second colormaking attribute, *chroma:* by adding three more paints, **the of color mixtures is increased**. color theory obscures this issue with its emphasis on the *balanced primary composition* of the new colors, and its interest to create a geometrically symmetrical color wheel.



the secondary (six hue) color wheel

Secondary Colors and Paints. We end up with **three secondary colors: red orange (ro), green (g), and blue violet (bv)**.

This six color secondary palette is a classic (and classy) minimal paint selection.

To take it for a test drive, I suggest you try the following six paints (again, click on the pigment color index name (http://www.handprint.com/HP/WCL/pigmt6.html#label) to identify the paint marketing names (http://www.handprint.com/HP/WCL/pigmt6.html#colors) used by different manufacturers):

primary light yellow : benzimidazolone yellow (PY154 (http://www.handprint.com/HP/WCL/watery.html#PY154)) or hansa yellow medium (PY97 (http://www.handprint.com/HP/WCL/watery.html#PY97))
secondary red orange : pyrrole orange (PO73 (http://www.handprint.com/HP/WCL/watero.html#PO73)) or cadmium scarlet (PR108 (http://www.handprint.com/HP/WCL/watero.html#PR108))
primary magenta : quinacridone magenta (PR122 (http://www.handprint.com/HP/WCL/waterc.html#PR122)) or quinacridone rose ("permanent rose", PV19 (http://www.handprint.com/HP/WCL/waterc.html#PV19R))
secondary blue violet : ultramarine blue (PB29 (http://www.handprint.com/HP/WCL/waterb.html#PB29)) or cobalt blue deep (PB73 (http://www.handprint.com/HP/WCL/waterb.html#PB73))
primary cyan : phthalocyanine blue GS (PB15 (http://www.handprint.com/HP/WCL/waterb.html#PB15)) or phthalocyanine cyan (PB17 (http://www.handprint.com/HP/WCL/waterb.html#PB17))
secondary blue green : phthalocyanine green BS (PG7 (http://www.handprint.com/HP/WCL/waterg.html#PG7)) or phthalocyanine green YS (PG36 (http://www.handprint.com/HP/WCL/waterg.html#PG36)); the best color match to magenta falls between these two greens.

These six paints provide **a substantial increase in mixing power** over the three paints in a primary palette, specifically in the intensity or purity of the most saturated mixed hues, as the following color mixing comparison makes plain.

primary and secondary paint mixtures

most saturated hue mixtures using three primary paints (left) or six secondary paints (right)

Although the primary triad paints are identical in both wheels, the addition of three saturated secondary paints significantly enhances the intensity of the deep yellow, yellow green, middle green, middle blue, blue violet and violet mixtures. (Notice that the violets and greens mixed from the primary triads are also darker valued than the equivalent pure pigment paints, and this darkening makes them look duller than they actually are but either way the eye easily notices a difference in color intensity.)

The secondary palette creates a lighter valued, more festive array of mixtures with much more evenly balanced chroma all around the color wheel. At the same time, the secondary palette can easily create rich darks (compare the center swatches) and simulate all the earth pigments. Nearly every hue in the hue circle can be mixed with a chroma that rivals the brightest pure pigment paint available for that hue.

Complementary Colors. The three new paints we've added to the color wheel are complementary colors (http://www.handprint.com/HP/WCL/color4.html#complementary) to the three primary paints. And this creates a fundamentally new color relationship a pair of colors that are in dynamic or reciprocal contrast. Color theory places a lot of importance on complementary color relationships in color mixing and design, so it's worthwhile to explore that story and see what it's worth.

In the standard (18th century (http://www.handprint.com/HP/WCL/color6.html#harris)) color theory, complementary colors are said to act as *color opposites,* creating a color relationship that is said to be either a **color contrast** or a **color antagonism**. Color contrast is demonstrated by viewing colors side by side (http://www.handprint.com/HP/WCL/book3.html#chevreul) in simple visual patterns where one color acts to enhance or alter the appearance of the other. Color antagonism is inferred from the effect of mixing complementary light wavelengths (which produces an achromatic white) or complementary paints (which produces an achromatic gray or black), each color destroying the hue of the other; or from complementary afterimages (http://www.handprint.com/HP/WCL/book3.html#goethe), where prolonged exposure to a color leads to a residual image of its complementary color. These *contrast* and *achromatic* interpretations can be combined, for example as was done by Ogden Rood (http://www.handprint.com/HP/WCL/book3.html#rood): *"Any two colors which by their union produce white light are called complementary. An accurate knowledge of the nature and appearance of complementary colors is important for artistic purposes, since these colors furnish the strongest possible contrasts."*

Let's start with the process: how exactly do we find the two "colors" that mix to white? The answer is different for additive or subtractive color mixing:

In additive color mixing, we take a white spectral reflectance curve (http://www.handprint.com/HP/WCL/color3.html#white) (or "white" spectral emission profile (http://www.handprint.com/HP/WCL/color10.html#white)) and divide it in two along *any* arbitrary boundary (illustration **a** at right). Alternately, we take the reflectance curve of a specific color and *subtract it* from the "white" reflectance curve, to produce a second residual reflectance curve. The two new profiles precisely define two new colors, and by definition the two colors can be mixed additively (by blending light beams, or spinning paint colors on a color top) to form a pure white. We then place these colors opposite each other on a visual color wheel (http://www.handprint.com/HP/WCL/vismixmap.html#CIELAB).

(In practice, either two or more different wavelengths of monospectral light are combined, trial and error, to find the complementary wavelengths that mix to white, or two or more paints are combined, trial and error, using an adjustable color top (http://www.handprint.com/HP/WCL/colortop.html), to find the combinations that visually mix to gray.)

We cannot use this divided reflectance profile method to find complementary colors in subtractive mixture. For example, splitting the profile horizontally into two 50% reflectance profiles produces two light grays, which do not mix to make white. So we use a different strategy:

In subtractive color mixing, we first find the exact mixture of three primary paints that creates an achromatic (light or dark gray) color. Then, we arbitrarily split this recipe into *two* new mixtures, for example (illustration **b** at right):

complementary paint mixtures **primary paintsgray recipe**
(in drops of paint)**one possible complementary mixture**
(in drops of paint) *color 1color 2* phthalocyanine cyan330. .33 benzimidazolone yellow3328. .5 quinacridone magenta3320. .13

These mixtures must by definition make a pure gray when combined, so the separate mixtures are complementary colors, and would be placed opposite each other on a mixing color wheel (http://www.handprint.com/HP/WCL/vismixmap.html#mixwheel).

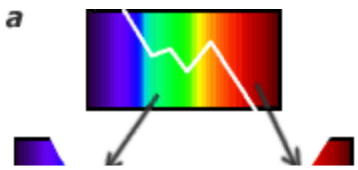
(In practice, usually two single pigment paints are mixed together, trial and error (http://www.handprint.com/HP/WCL/mixtable.html), to find pairs os single pigment paints that produce an achromatic or near neutral gray or black.)

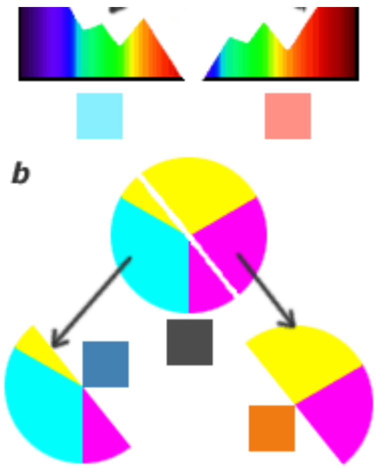
Complementary colors can be identified in other ways. In subtractive color mixing (http://www.handprint.com/HP/WCL/color5.html#theorysub), we can use colored filters, or dyes in solution, or colored powders, or oil or acrylic media to create similar mixtures and with these mixtures identify complementary hues. Each of these matched colors or mixtures would also be **mixing complements**.

In additive color mixing (http://www.handprint.com/HP/WCL/color5.html#theoryadd), we can find the monochromatic (single wavelength) lights that perfectly neutralize any single monochromatic light or emittance profile. We can use a *polarizing filter* to produce complementary colored fringes of any hue. Or we might even try to match the afterimage color (http://www.handprint.com/HP/WCL/color4.html#successive) that appears after we stare for a long time at a single color area. Color pairs identified in any of these ways would also be **visual complements**.

Now, if we try several of these different methods different mixtures of paints, powders and filters, or different mixtures of colored lights or spinning colored surfaces we might ask: are the complementary colors defined in these different ways the same? *The answer is "no"!*

The first surprise is that the **mixing complement will often be very different from the visual complement**; even the visual or mixing complements will differ among themselves, depending on the exact method we used to define them. The differences in watercolor paints are summarized in this table (http://www.handprint.com/HP/WCL/color16.html#comptable), using the major cool (blue violet to yellow green) paint colors as the standard of reference.





complementary colors
defined two ways:

(a) **additive complementaries**
for color vision, by splitting a
"white" spectrum in two;
(b) **subtractive complementaries**
for mixed substances, by splitting a
"gray" mixture of three or more
primary paints in two

The second surprise is that substance uncertainty (http://www.handprint.com/HP/WCL/color5.html#subprobs) creates insurmountable problems for subtractive color mixing. The issue is not just that the "mix to gray" results are dependent on the media used we could just accept watercolor paints as our standard. The problem is that when we use paints, the **"mix to gray" results are not consistent across hues** different colored paints will happily mix to gray with the same primary color! (The problem is described and illustrated in the section on painting in neutrals (http://www.handprint.com/HP/WCL/tech17.html#mixchart).) So we often end up with several different hues as mixing complements for a single paint which means the different hues must all be located at the same point on the color wheel!

So "complementary" color relationships depend on the media used to create the color mixtures, and in many media used for subtractive color mixing, complementary mixtures may not show a consistent relationship to the *hue* of the mixed substances.

A Complementary Grain of Salt. At the beginning we heard that "mix to gray" antagonism is proof of *"the strongest possible [color] contrasts."* We now can identify several problems with that claim:

paint mixtures cannot identify *visual* contrasts (visual complementary colors): **mixture antagonism does not define visual contrast**

paint mixtures cannot identify unique *color* contrasts: a single paint may allow several different paint colors (http://www.handprint.com/HP/WCL/tech17.html#mixchart) to create "antagonistic" mixtures with it

visual antagonism is a negative color relationship, and there is no evidence to suggest that a negative definition of visual color relationships can identify the positive color harmonies (http://www.handprint.com/HP/WCL/tech13.html) in a visual design (that is, it is hard to identify harmony by saying what harmony is *not*)

there are many different color wheels (http://www.handprint.com/HP/WCL/vismixmap.html), each based on a different plausible definition of complementary colors.

There is, then, no reason to accept color theory claims for fixed complementary color schemes. Color harmonies are often arbitrary symbol systems (http://www.handprint.com/HP/WCL/color17.html#theory) to begin with, and color combinations are a matter of taste and style, not color dogma.

If painters do want a complementary color framework, then the visual complementary colors (http://www.handprint.com/HP/WCL /color16.html#mixprobs) are most relevant to color design. These are, in fact, the complements advocated by Chevreul (http://www.handprint.com/HP/WCL /book3.html#chevreul), Rood (http://www.handprint.com/HP/WCL /book3.html#rood), and other classical color theorists. Viewers of paintings only see the finished color, not the work of color mixing, so the visible contrast between colors, not the mixing antagonism of paints, is what affects the design harmony.

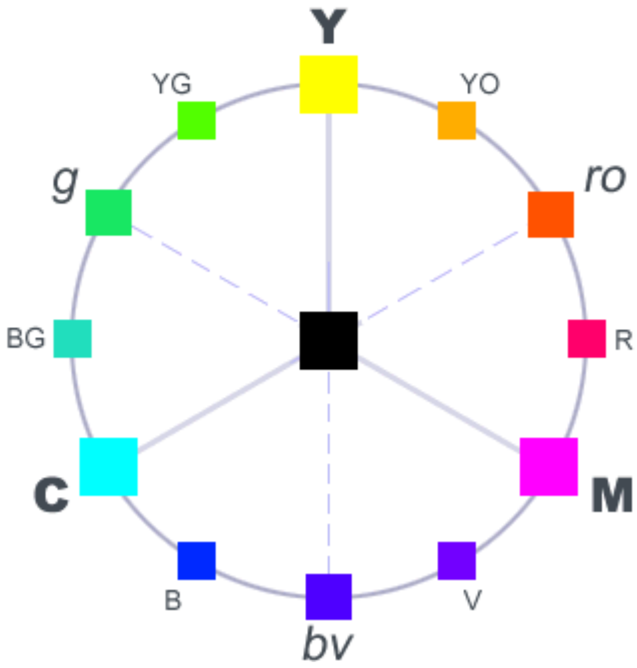
Where does that leave the color wheel? As a helpful but arbitrary construction that distorts as much as it clarifies the facts of color. Some artists bridle at this realization, and defend the geometrical clarity of color theory *it's so symmetrical, so perfect!* Others embrace the realization as permission to open their eyes to the marvelous richness of color mixing with actual paints instead of color ideas.

tertiary color wheel

The final step to a wider range of geometrically symmetrical colors takes us to the **tertiary colors**. These are defined as equal mixtures (at equal tinting strength) of a primary color with a secondary color *next to it* on the color wheel. This is identical to a mixture of two primary colors in the proportions 3:1 or 1:3, for example:

new color =50% magenta + 50% red orange new color =50%M + 50%(50%M + 50%Y) =50%M + 25%M + 25%Y =75%M + 25%Y

These tertiary colors form six new complementary color pairs each tertiary is directly opposite from another tertiary color. They also in theory divide the color wheel into **twelve equal hue steps** around the hue circle.



the tertiary (twelve hue) color wheel

Tertiary Colors and Paints. Reading counterclockwise from primary magenta, we have the following **six tertiary colors: red (R), yellow orange (YO), yellow green (YG), blue green (BG**, also called *sea green*)**, blue (B), and violet (V**, or purple**)**. These new colors define twelve equally spaced color points (http://www.handprint.com/HP/WCL/color16.html#tourwheel) around the hue circle, conventionally numbered from 1 (primary yellow), clockwise to 12 (yellow green).

If you want single pigment paints for each point on this new color wheel, I suggest using this palette (again, click on the pigment color index name (http://www.handprint.com/HP/WCL/pigmt6.html#label) to identify the paint marketing name (http://www.handprint.com/HP/WCL/pigmt6.html#colors) used by different manufacturers):

primary light yellow : benzimidazolone yellow (PY154 (http://www.handprint.com/HP/WCL/watery.html#PY154)) or hansa yellow medium (PY97 (http://www.handprint.com/HP/WCL/watery.html#PY97))

tertiary yellow orange: cadmium yellow deep (PY35 (http://www.handprint.com/HP/WCL/watery.html#PY35)) or hansa yellow deep (PY65 (http://www.handprint.com/HP/WCL/watery.html#PY65))

secondary red orange : pyrrole orange (PO73 (http://www.handprint.com/HP/WCL/watero.html#PO73)) or cadmium scarlet (PR108 (http://www.handprint.com/HP/WCL/watero.html#PR108))

tertiary red : pyrrole red (PR254 (http://www.handprint.com/HP/WCL/waterr.html#PR254)) or cadmium red (PR108 (http://www.handprint.com/HP/WCL/waterr.html#PR108))

primary magenta : quinacridone magenta (PR122 (http://www.handprint.com/HP/WCL/waterc.html#PR122)) or quinacridone rose ("permanent rose," PV19 (http://www.handprint.com/HP/WCL/waterc.html#PV19R))

tertiary violet : manganese violet (PV16 (http://www.handprint.com/HP/WCL/waterv.html#PV16)) or dioxazine violet (PV23 (http://www.handprint.com/HP/WCL/waterv.html#PV23))

secondary blue violet : ultramarine blue (PB29 (http://www.handprint.com/HP/WCL/waterb.html#PB29)) or cobalt blue deep (PB73 (http://www.handprint.com/HP/WCL/waterb.html#PB73))

tertiary blue : phthalocyanine blue RS (PB15:1 (http://www.handprint.com/HP/WCL/waterb.html#PB15)) or cerulean blue (PB35 (http://www.handprint.com/HP/WCL/waterb.html#PB35))

primary cyan : phthalocyanine blue GS (PB15 (http://www.handprint.com/HP/WCL/waterb.html#PB15)) or phthalocyanine cyan (PB17 (http://www.handprint.com/HP/WCL/waterb.html#PB17))

tertiary blue green : cobalt turquoise (PB36 (http://www.handprint.com/HP/WCL/waterb.html#PB36)) or cobalt turquoise light (PG50 (http://www.handprint.com/HP/WCL/waterg.html#PG50))

secondary green : phthalocyanine green BS (PG7 (http://www.handprint.com

/HP/WCL/waterg.html#PG7)) or phthalocyanine green YS (PG36 (http://www.handprint.com/HP/WCL/waterg.html#PG36))
tertiary yellow green : a *permanent green light* or *phthalo yellow green* (both convenience mixtures (http://www.handprint.com/HP/WCL/pigmt6.html#colors) listed under PG7 (http://www.handprint.com/HP/WCL/waterg.html#PG7) and PG36 (http://www.handprint.com/HP/WCL/waterg.html#PG36)).

This may seem like a large expenditure in paint, but it is worthwhile to use a large, systematic selection of colors. The experience will fine tune your paint mixing skill, and it will help you appreciate the strengths of a smaller palette.

Old & Modern Tertiary Colors. Here I should explain the conflicting definitions of tertiary colors that have appeared over the past two centuries.

The modern definition (as given, for example, in the *American Heritage Dictionary of the English Language,* 4th edition) is that a tertiary color is a mixture in equal proportions of **one primary color with a secondary color next to it**. The primaries are the modern primaries *magenta*, *yellow* and *cyan*. Because these tertiaries are actually the mixture of *just two* primary colors in 1:3 proportions (as shown above), they are, like the secondary colors, the most intense mixtures possible for that hue around the edges of the primary triad gamut.

These tertiaries stand for the modern conception of the color space as a that can be conveniently divided into 12 equal hue increments, like the hour marks on a clock face (http://www.handprint.com/HP/WCL/color17.html#step5).

These equal divisions mark out a maximally saturated hue circle that corresponds to the modern cultural and media emphasis on strongly saturated color in art, fashion and advertising. They also help the painter to anticipate the hue and saturation cost (http://www.handprint.com/HP/WCL/color14.html#satcost) of any two paint mixture: the greater the number of intervals between the paint hues on the tertiary color wheel, the duller their mixture will be. And this is exactly how hue differences are defined and color mixtures explained (http://www.handprint.com/HP/WCL/color14.html#harris) by Moses Harris (http://www.handprint.com/HP/WCL/color6.html#harris) in his *Natural System of Colours* (1766).

The original 18th century (http://www.handprint.com/HP/WCL/color14.html#chevreul) color mixing conception was based on the traditional primaries *red, yellow* and *blue*. More important, it defined three tertiary colors as **an equal mixture of *two* secondary colors**. So in Victorian era painting treatises (as quoted under the entry for "tertiary" in the *Oxford English Dictionary,* 1933), only three tertiary colors are referenced, as the mixture of **two secondary colors** in equal amounts which gives the new colors *brown, olave* and *slate* (in Harris) or *russet, olive* and *citrine* (in 19th century treatises).

These 18th century tertiary colors stood for the dull, unsaturated or near neutral colors *inside a color triangle,* not the hues of maximum chroma or saturation along its sides. By mixing two secondaries, painters had a simple and reliable way to create a familiar series of dulled colors across the interior of the color space, which could be intermixed to create the countless dull color variations of nature that were important to 18th and 19th century painting styles and color systematists. And this is also how tertiary colors are defined and explained by the naturalist Moses Harris in his color wheel treatise, who highlights them as a separate color wheel consisting of orange, green and violet mixtures.

The traditional tertiary colors highlight the geometrical difference between the traditional representation of the primary triad as a circle and its representation as a triangle. As shown in the diagram (right), the mixture of two secondary colors is, in the analytical , identical to the mixture in equal proportions of **a primary color and its *complementary* secondary color**. So although color theory dogmatists explain that two complementary colors in equal proportions mix a gray, while two secondary colors in equal proportions make a tertiary color, in fact both mixtures contain identical proportions of the three primary colors, and therefore must produce the same color mixture:

tertiary[brown] =**50% secondary[orange]** +
50% secondary[purple] =**50%(50%R** + **50%Y)** +
50%(50%R + **50%B)** =**25%R** + **25%Y** + **25%R** + **25%B** =50%R + 25%Y +
25%B =**50% primary[red]** + **50% secondary[green] neutral[gray]** =**50%
primary[red]** +
50% secondary[green] =**50%R** + **50%(50%Y** + **50%B)** =50%R + 25%Y +
25%B

The confusion here is that a color wheel (used to explain complementary color mixtures) and a color triangle (used to explain tertiary color mixtures, after J.W. von Goethe (http://www.handprint.com/HP/WCL/goethe.html#goethewheel)) define different color mixture proportions. Attempting to mix a gray or neutral color with a 50%/50% mixture of a primary and its complement assumes a *color wheel* geometry where all hues are equally far from the neutral center, and therefore have the same saturation or hue purity. In a *primary triad triangle* the red primary is twice as far from the neutral center as the green mixture, because it is more saturated. Therefore only half as much red is necessary to neutralize the green:

neutral [gray] =**33% primary red** +
33% primary yellow +
33% primary blue =33% primary[red] +
66% secondary [green]

The problem lies in the attempt to make color mixing geometrically neat. Actual paint proportions will typically not resemble any of these abstract recipes from a circular or triangular geometry, because the relative tinting strengths (http://www.handprint.com/HP/WCL/intstud.html#step15) of the red and green "colors" will vary depending on which *paints* are used. This illustrates the confusions that can be created by color theory principles formulated in terms of *colors* rather than *paints*.

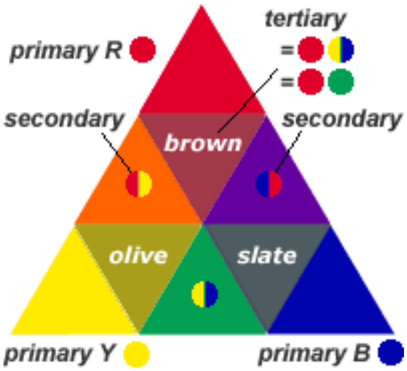
Final comment: *tertiary* means that these mixtures are third in a sequence. The "primitives" (as they were called in the 18th century) are red, yellow and blue (*primary* or first rank), their equal mixture makes new colors (*secondary* or second rank), and the equal mixture of secondaries makes new colors (*tertiary* or third rank). Yes, the tertiaries contain all three primaries but so do gray and black, and they are not tertiary colors.

more is less? a gamut comparison

Now comes a surprise: although it's bursting with colorful paints, the tertiary color wheel is rather uninteresting. It does not create a fundamentally new color relationship, in the way the primary triad wheel creates all mixed hues, or the secondary color wheel creates complementary color pairs. It just adds six new complementary pairs to the three in the secondary color wheel.

What's more, although there are trivial saturation costs (http://www.handprint.com/HP/WCL/color14.html#satcost) among the mixtures of adjacent colors on this twelve color wheel, the saturation costs in mixtures of adjacent colors on the are not any worse.

Rather than prove the point by the visual , we'll do it using the more formal method of a **gamut comparison** based on spectrophotometric measurements of actual watercolor paint mixtures. Gamut comparisons are common in the color imaging and color printing industries, and painters should be familiar with the basic concept.

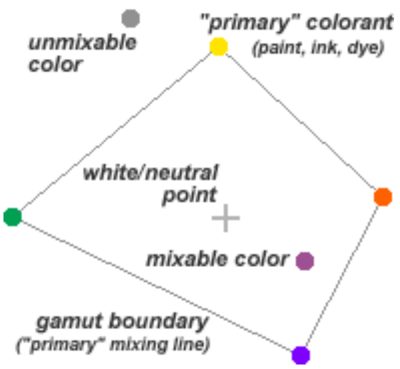


the 18th century "color theory" definition of a tertiary color

showing that a tertiary color mixed
from two secondary colors is
identical to the mixture of
a primary and a secondary color

A **gamut** (at right) is *the domain of all colors that can be mixed from a specific set of fundamental colors* which may be the traditional three primary colors or may be four or more palette colors. In a gamut these "colors" are always actual physical colorants: watercolors on a palette or inks in a print job or dyes in a color film or phosphors in a television monitor. Always, **the gamut depends on specific colorants in the media used to mix the colors**, and changing from one medium to another or exchanging one fundamental color for another almost always changes the gamut, sometimes drastically. Measuring whether or how much color mixtures will be affected by a change in colorants or media, and computing how to translate image colors from one medium to another so that the image "looks the same" to an average viewer, are the major reason for gamut comparisons in color rendering technologies.

The **gamut boundaries** represent the most intense or saturated colors that the colorants can mix from the lightest to darkest values. These boundaries come to points or corners defined by the "primaries" or fundamental colorants, and form mixing lines or mixing planes between every pair or triad of adjacent primary colorants. If the fundamental or primary colorants are chosen so that the gamut contains a **white point** or neutral gray mixture, then the fundamental colorants can mix all hues. Any color that can be matched by a mixture of two or more fundamental colorants is said to be *inside the gamut;* any color that cannot be matched because it is too intense, too light or too dark is said to be **outside the gamut** and is an unmixable color.

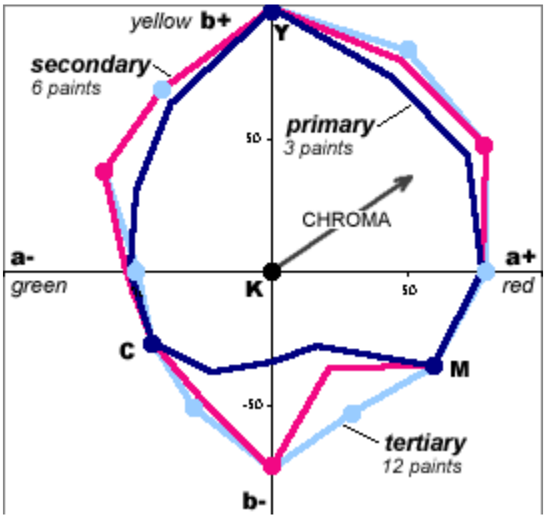


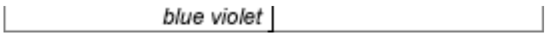
a gamut showing the chroma limits but not the lightness range

Gamut comparisons are made by representing different gamuts within the same standardized colorimetric space. Usually CIELUV (http://www.handprint.com/HP/WCL/color6.html#CIELUV) or CIELAB (http://www.handprint.com/HP/WCL/color7.html#CIELAB) is used for this purpose. The CIE color models enclose the space of all possible colors, and define color locations by spectrophotometric measurements, which provides an objective frame of reference to judge the shape and size of a gamut and to compare different gamuts with each other. The example at right compares in CIELAB the "millions of colors" Apple RGB (computer monitor) gamut, its subset the 256 color ("web safe") gamut, and the CYMK (printing ink) gamut, with contouring lines to suggest their three dimensional shape. Note the range of purples, reds and greens available in a computer monitor but unmixable in the CYMK system. Because monitor colors are created by tiny colored lights, they can produce greater luminance contrasts, and higher color saturation, than reflective prints.

The **lightness or brightness range** of the media is always part of the gamut, although in most gamut illustrations (like the one at right) it is the dimension perpendicular to the viewer. But the gamut of a "full color" process in any imaging media is always three dimensional, like a sphere or cube. (The gamut of a black and white printer or grayscale image is simply a line, like a value scale, from its darkest to lightest values; the gamut of a duochrome process is a triangle, with the third corner representing the pure colored ink.) And gamuts are always sensitive to the specific context in which colors are measured or judged. The gamut of a television is reduced if sunlight is falling on the screen, just as the gamut of a printer's ink system becomes smaller if colors are printed on gray paper, or with coarse halftone mixtures, or the print is viewed in dim light rather than sunlight.

Now that you understand what a gamut is good for, here is the gamut on the CIELAB a*b* plane (http://www.handprint.com/HP/WCL/labwheel.html) of the 12 tertiary colors in watercolor paints. The colors are either the most saturated single pigment paint available for that hue (as listed above for the) or is the matching color mixture using the two best paints listed for the or palettes. In each case, the actual paint locations are indicated by large dots.





the gamut or maximum chroma of tertiary colors

chroma of the twelve most intense tertiary paints (light blue line), and the same paints also found in or mixed with the primary palette (dark blue line) or secondary palette (red line). (Chroma calculated on the CIELAB a*b* plane (http://www.handprint.com/HP/WCL/labwheel.html), with CIELAB red placed at left to match the standard color wheel.)

As you can see, the twelve fundamental colors in the tertiary color wheel do not furnish *any* improvement in chroma over the six fundamental colors in the secondary color wheel (with the sole exception of purple, which represents the addition of dioxazine violet). So we don't gain either a new color relationship or more intense color mixtures by *doubling* the number of paints in the palette!

If our philosophy is "bang for the buck," then the secondary palette (http://www.handprint.com/HP/WCL/palette4e.html) is clearly the most efficient of the three. It achieves the greatest range of color chroma with the smallest number of paints, and it provides a powerful set of three readymade complementary color pairs that are easier to work with than the paints in either the primary triad (http://www.handprint.com/HP/WCL/palette4c.html) or split primary (http://www.handprint.com/HP/WCL/palette4r.html) palettes where *all* visual or mixing complements and *all* near neutral dark grays, must be mixed from at least three paints.

Artists Mix Paints, Not Colors. So why don't all artists use this best of all possible palettes? Because our focus all along has been on *maximum chroma* and for many artists chroma is not by itself important. What matters to them is the specific selection of *paints*.

Some artists use a large palette (http://www.handprint.com/HP/WCL

/palette4t.html) in order to tackle complex design problems, or introduce wider variations in pigment texture, transparency, or handling attributes, or simply to minimize the task of mixing paints to produce specific colors. Others use a reduced palette (http://www.handprint.com/HP/WCL/palette4d.html) of four or six paints to create a more cohesive color harmony, or they choose paints with lower chroma (http://www.handprint.com/HP/WCL/palette4h.html) in order to achieve subdued, classicizing landscape effects (http://www.handprint.com/HP/WCL/palette4w.html). Most artists seek a middle ground: they rely on a preferred set of about 10 or 12 paints (http://www.handprint.com/HP/WCL/palette4v.html) to meet most of their painting needs, but occasionally add one or more paints to this basic palette to get a specific saturated hue, pigment texture, or color effect.

By itself, a color theory color wheel can't guide your paint choices or palette design. It emphasizes hue over value and chroma, geometrical symmetry over gamut shape, and abstract color concepts over actual paints. It tells you nothing about paint selection strategy. So by negative example the tertiary wheel illustrates that there is more involved in palette design than abstract color geometry: artists mix paints, not "colors" (http://www.handprint.com/HP/WCL/color5.html#experience).

color names

The tertiary color wheel does serve one useful purpose: it divides the hue circle into equal hue steps defined by explicit color mixtures, which allows us to locate specific color names and match them to specific paint examples. The tertiary colors can be used as reliable landmarks, like Paris metro stops, to map out a convenient and standard color nomenclature (http://www.handprint.com/HP/WCL/color16.html#notes) that can **locate a hue or color just by naming**

it.

The color names available in any language include the basic color categories (http://www.handprint.com/HP/WCL/color2.html#language) and color names acquired through the demands of the technologies or knowledge domains (http://www.handprint.com/HP/WCL/color7.html#evolution) that require colors to be mixed, identified or labeled. There are conventional ways to qualify or combine these basic color terms in order to name colors blends or color variations in chroma or lightness. These conventions control how names are attached to colors and how a color is identified or recognized from its name.

The Universal Color Language. Probably the most widely recognized standard naming system in English is **The Universal Color Language** (UCL), first published by the Inter-Society Color Council and the National Bureau of Standards (USA) in 1955 and extensively revised for the 6th edition in 1976. Each of the 267 UCL color names is mapped onto a unique color sample in the Munsell Color System (http://www.handprint.com/HP/WCL/color7.html#Munsell). An object color is compared to the set of 267 Munsell color samples, and the closest color match identifies the standard color name that should be used to describe the object color.

The UCL system is designed as follows:

There are **13 basic color names**: *red, pink, orange, brown, yellow, olive, green, blue, violet, purple, white, gray* and *black*.

The basic color names of colors that are next to each other in the Munsell color space combine to form **34 compound color names**: *reddish purple, reddish gray, reddish orange, reddish brown, reddish black, pinkish white, pinkish gray, brownish pink, brownish gray, brownish black, yellowish white, yellowish pink, yellowish brown, orange yellow, greenish yellow, olive brown, olive green, olive gray, olive black, yellowish* *green, greenish white, greenish gray, greenish black, bluish green, greenish blue, bluish white, bluish gray, bluish black, purplish blue, purplish white, purplish gray, purplish black, purplish pink* and *purplish red*.

The 47 basic and compound color names are modified by a system of overlapping lightness and/or chroma adjectives:

vivid for the color at **maximum chroma** (which defines a specific lightness (http://www.handprint.com/HP/WCL/color11.html#valchrom) for every hue);
brilliant, strong, deep or *very deep* for the light to dark **lightness variations at high chroma**;
very light, light, moderate, dark or *very dark* for the light to dark **lightness variations at average chroma**; and
whitish, very pale, pale, grayish, dark grayish or *blackish* for light to dark **lightness variations at low chroma**.

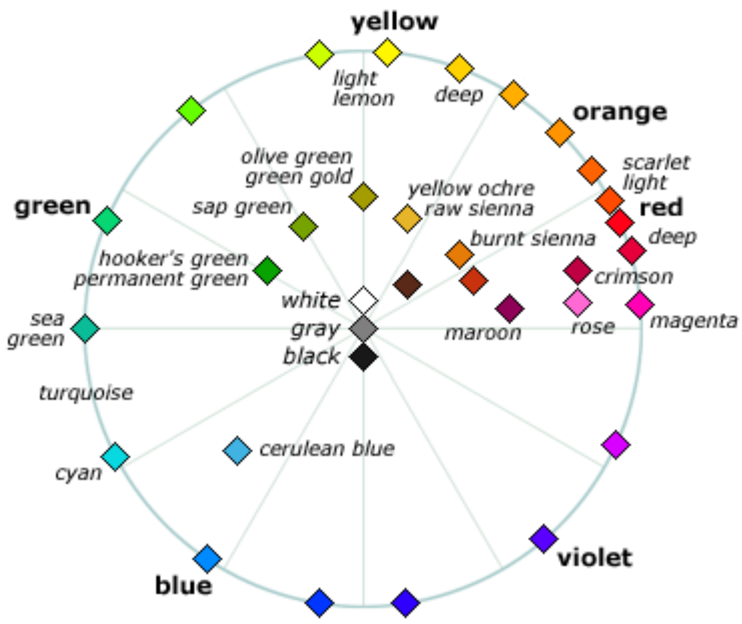
The actual combination of lightness/chroma modifiers is different for every color name, but all possible object colors can be assigned a color label.

The UCL nomeclature has been used to standardize color terms in biology, botany, horticulture, agriculture, interior design, marketing, textiles, colorant manufacturing, plastics, geology and even stamp collecting. This Azalea Society (http://www.azaleas.org/index.pl/azcolorhelp.html#ucl) page shows how a variety of flower descriptive names can be clarified, standardized and compared through the UCL nomenclature note that *cinnamon, bronze, buff, tan* and *tawny* are all essentially the same color.

The UCL is a useful reference for artists, as it establishes a consistent usage for terms such as *deep*, *pale* or *brilliant* and objective (if arbitrary) boundaries between color categories such as *orange* and *yellow pink* or *blue green* and *bluish green,* all within a color grammar that conforms to graceful English usage.

Commercial Paint Names. Most artists learn color names as defined by paint companies. So it is necessary for artists to learn the naming conventions that art materials manufacturers generally rely on to devise their paint marketing names (http://www.handprint.com/HP/WCL/pigmt6.html#colors) or paint "colors".

The diagram locates the most important and consistently used color names within my .



standard hue names around the hue circle

In general commercial paint color names can be interpreted as follows:

1. There are six basic color categories (http://www.handprint.com/HP/WCL/color2.html#language): **red**, **yellow**, **green**, **blue**, **black** (dark) and **white** (light). Three mixture colors, **orange**, **purple** (or violet) and **gray** are commonly added in English, for a total of nine basic colors. These are located in capital letters in the diagram.

2. Within each color category, the "typical", "best" or "pure" hue in the category has claim to the unmodified color category name: *red* or *blue*. If you want to

emphasize that the color is not tinted with any other color, add **middle** or **medium** to the color name: *medium red*, *middle blue*. (*Pure* or *true* "pure blue" or "true red" are not used.)

3. Within each of the six basic hue categories, **a hue that is shifted toward primary yellow is "light" and a hue that is shifted toward blue violet is "deep"**. For example: *cadmium red light* is a red shifted toward yellow (orange), or a scarlet red; *cadmium red deep* is a red shifted toward blue (maroon); a bluish violet is a violet deep. That is, **light** and **deep** describe *hue* rather than *lightness* or value. To mark this, they are usually **placed after the hue name**, to avoid confusion with luminance related lightness. Thus, *red light* (scarlet), not *light red* (pink); or *orange deep* (scarlet), not *dark orange* (brown).

4. Alternately, **a color that is close to an adjacent color is named by putting the adjacent color name first**, in the same way we put adjectives before nouns. Sometimes "ish" is added to clarify which term modifies which. Thus, a blue that is close to green is a *green blue* (or *greenish blue*); a red that is close to orange is an *orange red* or *orangish red*. (*Yellowish red* is acceptable, but unusual and ambiguous. See for example this Hue Indication Chart (http://www.sdc.org.uk/publications/huechart.htm) used by the Society of Dyers and Colourists (SDC) to describe pigment or dye color.)

5. Colors with high chroma are sometimes (but not consistently) labeled **vivid, brilliant** or **bright**; **pale** is sometimes used to indicate a pastel (whitened) color, and **deep** a saturated, dark valued color, conflicting with the more common usage described in point 5. In general, blackened or whitened colors are not explicitly named as such (**dull** having the negative connotation of "inferior" or "lesser quality").

6. Many color terms are tied to hues of a specific lightness and/or chroma: **rose** is a light valued bluish red, **magenta** is a mid to light valued violet red, **cyan** is a

mid to light valued green blue, **ochre** is a mid valued dull orange yellow, and so on.

If a paint name is outside these naming conventions, then you are in much less certain territory. However the following points are useful:

7. Many of the dull, dark valued or whitish colors between yellow and red are broken out as specific color categories: **olive** (dull yellow or green yellow), **tan** (dull yellow), **gold** (dull orange yellow), **brown** (dark or dull deep yellow or orange), **maroon** (dark dull red), **pink** (light red or light violet red), **crimson** (dark violet red) or **rose** (light violet red). These color names can modify or be modified by other color names ("yellow gold," "violet rose," etc.), or by adding "light" or "deep" as defined in rule 3 ("deep gold" for "orangish gold").

8. A second group of specialized color names includes the family of earth colors (http://www.handprint.com/HP/WCL/earthp.html) almost always golds, tans and browns made from iron oxide (http://www.handprint.com/HP/WCL/palette1.html#earth) pigments. These are by far the paints most often sold under traditional or historical color names, including *raw sienna, burnt sienna, yellow ochre, gold ochre, french ochre, raw umber, burnt umber, indian red, english red, venetian red, red ochre, mars yellow, mars red, mars brown, brown madder, brown ochre, naples yellow, brown stil de grain, cassel earth, caput mortuum, mummy, dragon's blood, vandyke brown, sepia, pozzouli earth, violet umber, rose madder,* and so on *ad nauseum*. In nearly all cases these paints are actually made of modern synthetic iron oxide pigments, not the natural earths that gave the "color" its traditional name.

9. Most green paints are convenience mixtures (http://www.handprint.com/HP/WCL/waterg.html#convenience) of a green and yellow or (nowadays rarely) blue and yellow paint, and these paints are also given historical color names that provide vague guidance about the actual color quality *emerald green, permanent*

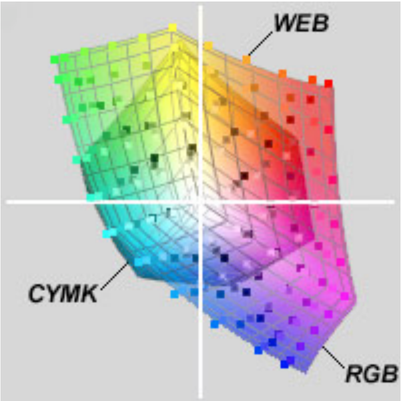
green (light or deep), hooker's green (light or deep), terre verte, sap green as well as descriptive color names such as *olive green, leaf green, vivid green, bright green,* etc.

10. Historically there have always been more pigments available on the warm than on the cool side of the color wheel. As a result, nearly all red, orange or yellow pigments are modified by hue names, but the violet, blue and green pigments are simply called after their chemical or mineral names *manganese violet, ultramarine violet, cobalt violet, dioxazine violet, indanthrone blue, ultramarine blue, cobalt blue, prussian blue, phthalo blue, cobalt turquoise, phthalo green, viridian, chromium oxide green, cobalt green, cadmium green, prussian green,* etc. (Blue convenience mixtures are infrequently offered.) You must learn the characteristic color implied by each pigment name: *ultramarine blue* is a dark, high chroma reddish blue, *manganese blue* is a mid valued, high chroma greenish blue, and so on.

11. Chemical sounding synthetic organic pigment names (*phthalocyanine, benzimidazolone, pyrrole, dioxazine, indanthrone*) are commonly replaced by the moniker *permanent,* which is a 19th century labeling convention that has nothing to do with the actual lightfastness of the paint! Pigment names are also commonly replaced by proprietary or brand names (*winsor, blockx, scheveningen, australian, thalo,* etc.). Occasionally the term *spectrum* is used to denote a primary red, yellow or blue that has a balanced hue and high chroma.

Because these color names are primarily chosen for their marketing impact, and the pigments they name are so diverse, you eventually learn that this is an area where systematic color naming is hard pressed by marketing creativity. Experience with the retail paint market is necessary to find your way through the labeling clutter. The labeling conventions described here provide some guidance.

Hue, Chroma & Lightness Categories. Throughout this site I use a relatively simple, adaptable and unambiguous color naming scheme, based on the three colormaking attributes (http://www.handprint.com/HP/WCL/color3.html#colormaking) of hue, chroma and lightness.



a CIELAB comparison in three dimensions of the RGB, CYMK and "web safe" gamuts

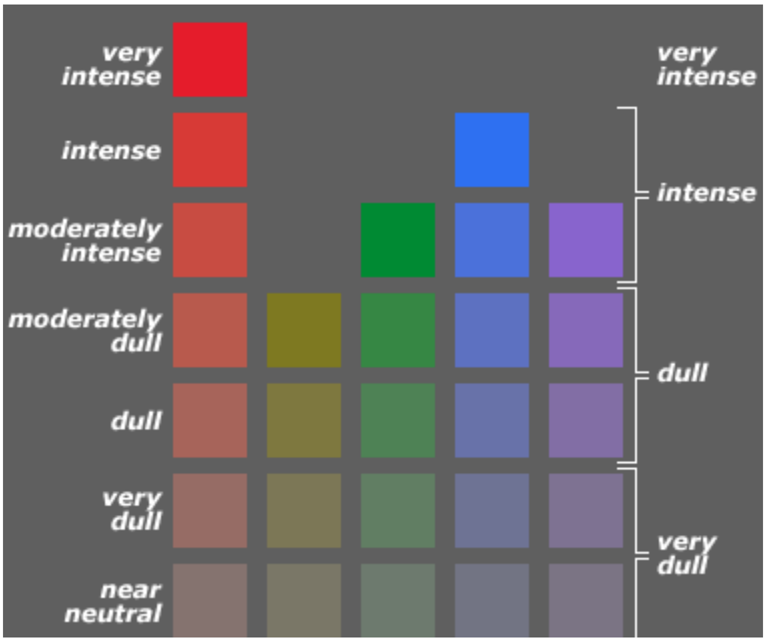
Lightness Categories. The diagram (right) shows the lightness categories used in the guide to watercolor pigments (http://www.handprint.com/HP/WCL/waterfs.html). These are the median lightness values of the CIECAM J scale (http://www.handprint.com/HP/WCL/color7.html#CAMlightness) corresponding to each lightness label. Note that the terms *near white* and *near black* only apply to colors with perceptible hue content, such as yellow or blue violet. If these lightness gradations are considered a gray scale then the end categories become *white* and *black*.

This lightness scale has been *gamut mapped* into the range of watercolor paint values to create a value range (http://www.handprint.com/HP/WCL/pigmt8.html#valrange) scale. This was done by subtracting **J** from the lightness of a white watercolor paper, as explained here (http://www.handprint.com/HP/WCL/pigmt8.html#valrange). The lightness examples within each step suggest the approximate lightness that each category represents. The categories correspond to 10 unit intervals on the **J** scale with the lowest interval (**J**

Most studies of color categorization show that humans can reliably distinguish only about 7 categories on a continuum, so this scale is too complex for easy use. It can be collapsed into 5 categories, using only the underlined terms. These correspond to lightness **J** intervals of 85-96 (*near white*), 65-85 (*light valued*), 45-65 (*mid valued*), 25-45 (*dark valued*) and less than 25 (*near black*).

Chroma/Saturation Categories. The chroma categories used on this site are explained here (http://www.handprint.com/HP/WCL/pigmt8.html#chroma). They range from *neutral* and *near neutral* to *very intense* and *supersaturated*. The description of pigment chroma provided in the guide to watercolor pigments (http://www.handprint.com/HP/WCL/waterfs.html) is based on the average CIECAM chroma (http://www.handprint.com/HP/WCL/color7.html#CAMchroma) for all paints listed.

In general, even trained human observers find it difficult to judge chroma accurately by eye, as it has a different visual impact depending on the lightness and hue of the color. But the general impact of color intensity can be communicated with just five categories: *gray*, *very dull*, *dull*, *intense* and *very intense,* with the boundary between *intense* and *dull* judged simply as color that seems to contain more hue than gray, or more gray than hue. The examples below suggest the approximate chroma intensity each category would cover.



illustrative red, yellow, green, blue and purple chroma intervals

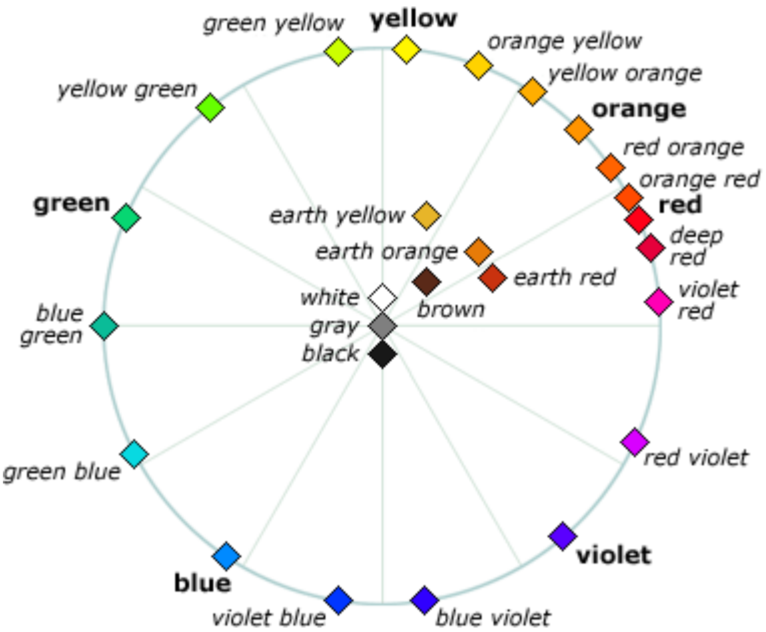
all hues shown at mid value (**J** = 55)

As this diagram shows, the chroma categories provide approximately equal perceived differences in chroma across all hues, but the maximum possible chroma within each hue is different. Thus a mid valued yellow never appears much more than dull, and this is inherently because of the way our color vision is structured (intense yellows only appear at high lightness).

Higher chroma is possible in greens, blues and purples, but here the gamut of color rendering media usually (and certainly, in watercolors) imposes limitations that are well inside perceptual limits. It is mostly oranges and reds that achieve the highest chroma, both because our perceptual limits allow it and because pigment chemistry can produce the "warm cliff" profile (http://www.handprint.com/HP/WCL/color12.html#cliff) in pigment reflectance curves that nearly matches an optimal color (http://www.handprint.com/HP/WCL/color3.html#optimalstimuli) with the same hue and lightness.

Hue Categories. The hue categories used on this site correspond to the straightforward system introduced by Moses Harris (http://www.handprint.com/HP/WCL/color6.html#harris) in 1766, but with the insertion of the hue category *deep red* between *red* and *violet red,* and the addition of hue categories for the "earth" (iron oxide) pigments and synthetic organic pigments that resemble them. These new categories reflect the subtle perceptual discriminations usually applied across the "warm" colors, and also respond to the very large proportion of pigments that are found in the yellow, orange and red range of hues.

The application of these hue labels to the pigments listed in the guide to watercolor pigments (http://www.handprint.com/HP/WCL/waterfs.html) is based on the average CIECAM hue angle (http://www.handprint.com/HP/WCL/color7.html#CAMfunctions) for all paints in each category. The table below summarizes these hue categories in relation both to the spectral hue categories (wavelength hues) and the common watercolor pigments that best exemplify each hue.



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

standard hue categories *wavelength spanmatching pigmentsymbolhue name* 640 700**PR188OR**orange red 620 640**PO73RO**red orange 600 620**PO20Oorange** 590 600**PY110YO**yellow orange 580 590**PY65OY**orange yellow 570 580**PY154Yyellow** 560 570**PY184GY**green yellow 530 560**PY3+PG7YG**yellow green 500 530**PG36Ggreen** 490 500**PG7BG**blue green 480 490**PG50GB**green blue 460 480**PB35Bblue** 440 460**PB29VB**violet blue c560 440**PV15** [blue]**BV**blue violet .... *extraspectral hues* .... c530 c560**PV23Vviolet** c510 c530**PV49RV**red violet c490 c510**PR122VR**violet red 700 c490 **PR209 Rred Note**: Hue boundaries rounded to the nearest 10 nm. Spectral hue boundaries are arbitrary; see the discussion here (http://www.handprint.com/HP/WCL/color1.html#spectrum). "**c**" means "complement of" [wavelength] for extraspectral hues (mixtures of "orange red" and "blue violet" light).

Sources: complementary hues from Wyszecki & Stiles (1982); hue boundaries from my own CIECAM spectral hue scaling of watercolor pigments, Munsell hue categories and spectral wavelengths.

The hues *violet red, green yellow* and *green blue* correspond to the three optimal subtractive primary colors (http://www.handprint.com/HP/WCL/color5.html#idealsub) identified through colorimetric simulations and verified in the synthesis of surface colors (http://www.handprint.com/HP/WCL/color19.html#yellowcyancircuits). Note that these are not necessarily the primary hues used in modern photographic or CYMK printing technologies.

The coverage of the hue circle provided by modern pigments is relatively sparse across the blues and extremely sparse across the greens and violets. (See for example the pigment distribution in the artist's color wheel (http://www.handprint.com/HP/WCL/cwheel06.html).) The representative pigments listed do not provide nearly as adequate color exemplars across the "cool" hues as they do across the "warm" hues.

The fact that the visual hue categories are also more crowded between *yellow* and *red* suggests that variations in those hues are perceptually and psychologically more significant.

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

VALUE RANGE

CATEGORIES

1-7

8-17

18-27

28-37

38-47

48-57

58-67

68-77

> 78= near white

= very light valued

= light valued

= moderately light valued

= mid valued

= moderately dark valued

= dark valued

= very dark valued

= near black

MATCHING LIGHTNESS

CATEGORIES

90-96

80-89

70-79

60-69

50-59

40-49

30-39

20-29

= near white

= very light valued

= light valued

= moderately light valued

= mid valued

= moderately dark valued

= dark valued

= very dark valued

= near black

handprint.com (http://www.handprint.com/HP/WCL/color13.html)