handprint : mixing with a color wheel

handprint.com (http://www.handprint.com/HP/WCL/color14.html)

mixing with a color wheel

Finally we get to the first practical application of color: how to mix colors with paints, using a color wheel as a guide.

A simple but powerful mixing concept, the geometrical mixing method (http://www.handprint.com/HP/WCL/color2.html#mixingcircle), lets us visualize color mixtures within a traditional color wheel (http://www.handprint.com/HP/WCL/color13.html). This method uses the distance and midpoint between any two paints on the color wheel to estimate the saturation and hue of their mixture.

The geometrical method explains , the unavoidable dulling of color created when we mix any two or more colored lights or paints, regardless of their hue. We encountered saturation costs in the demonstration of mixing step scales (http://www.handprint.com/HP/WCL/color13.html#mixingsteps) for primary triad mixtures.

The geometrical method works very well for mixtures of light in additive color mixing (http://www.handprint.com/HP/WCL/color5.html#theoryadd). It is much less precise for subtractive color mixing because of the many significant differences (http://www.handprint.com/HP/WCL/color5.html#subsubtract) between the two color mixing processes. Assuming a color wheel can be used equally well in both cases is the .

The solution is not to discard the color wheel, but to use it intuitively and alertly, as a . This is the basic mixing method explained here.

The key issue is that artists mix paints, not colors (http://www.handprint.com/HP/WCL/color5.html#experience). Nearly all the magic in a painting and the difficulties in color mixing arise from the richness and complexity of the color materials, not from the abstract experience of color itself. It's important not to let color theory or an abstract mixing method distract you from thinking in terms of specific paints and their unique effects when combined on paper. The is one example of color dogma getting in the way of effective paint selection.

saturation costs

The easiest way to understand color mixing with a color wheel is through the study of **saturation costs** the reduction in the hue purity (http://www.handprint.com/HP/WCL/color3.html#colormakingchroma) (chroma or saturation) that results from the mixture of two or more colors.

Newton's concept of a hue circle (http://www.handprint.com/HP/WCL/color2.html#newtoncircle) was devised specifically to permit a geometrical definition (http://www.handprint.com/HP/WCL/color2.html#mixingcircle) of the colors that result from additive mixtures of light. It builds on these concepts:

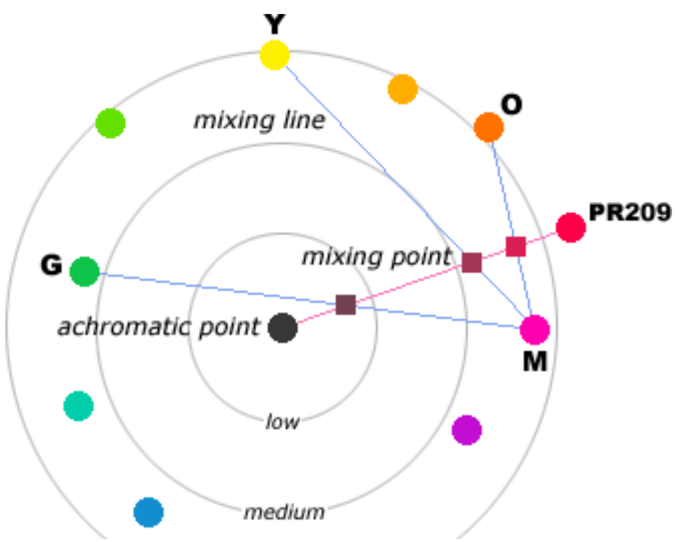
the hue (http://www.handprint.com/HP/WCL/color3.html#colormakinghue) of a color is defined by its *hue angle* or location around the circumference of the hue circle (usually measured in degrees from a zero point at red) the chroma (http://www.handprint.com/HP/WCL/color3.html#colormakingchroma) of a color is defined by its *distance from the center* of the circle

pure neutrals (white, gray or black) are at the center, and therefore have no hue angle and no saturation

complementary colors (http://www.handprint.com/HP/WCL/color13.html#compprobs) (which mix to a pure neutral) are *directly opposite* each other on the circle

the color of a mixture is found as the "center of gravity" of all the hues (light wavelengths) in the mixture, which is found as the average of the separate wavelengths weighted by their proportional "quantity" (brightness or tinting strength).

Let's first demonstrate Newton's geometry as it would apply to the mixture of different colors of paint on the artists' color wheel (http://www.handprint.com/HP/WCL/cwheel06.html). We start with the locations of several different paints around the hue circle. Our goal is to match the *hue* of a specific paint, quinacridone red (PR209 (http://www.handprint.com/HP/WCL/waterr.html#PR209)).



saturation costs on a hue circle

In each case, to estimate the appearance of the color mixtures possible with two paints, we draw a **mixing line** that connects the two paints being mixed (blue lines in the diagram). Then:

The **hue** of the mixture is defined by the hue angle (http://www.handprint.com/HP/WCL/color7.html#hsv), a line drawn from the center of the wheel through the midpoint to the circumference (red line in the diagram). The location of the line at the circumference identifies the hue of the mixture.

The **chroma** of the mixture is the distance of the midpoint from the center of the wheel to the circumference (concentric circles in the diagram): the closer the midpoint is to the center, the duller or grayer the mixture will be.

Now we can show, if we measure distance as the difference in the hue angle, that **paints farther apart on the color circle produce duller mixtures**. Compare the distance from the achromatic (black, gray or white) center of the color wheel to the point where the three mixing lines in the figure intersect the hue angle of quinacridone red.

1. The mixture of magenta (**M**) and orange (**O**) is close to the outer edge of the wheel, and so will have a high saturation; the mixture will be a deep red.

2. The mixture of magenta and yellow (**Y**) is somewhat displaced from the circumference of the wheel, so it will have a moderate saturation and appear to be a maroon.

3. The mixture of magenta and green (**G**) is very close to the center of the wheel,

so it will have a very low saturation and will appear to be a violet brown.

Note that mixing complementary colors (http://www.handprint.com/HP/WCL/mixtable.html) are located approximately opposite each other on the color wheel, so that their mixing line will pass through the achromatic center of the color wheel they mix to make black or gray.

This illustrates the general strategy that painters use to mix colors. If they want to make a saturated mixture, they mix the two paints that are both close to the hue they want to match; if they want a dull mixture, they mix two paints of which one or both are far from the hue they want to match.

Obviously, **dull paints produce dull mixtures** because they are *already* closer to the neutral gray center of the color wheel. Venetian red (PR101 (http://www.handprint.com/HP/WCL/watere.html#PR101)) and yellow ochre (PY43 (http://www.handprint.com/HP/WCL/watere.html#PY43)) will produce a much duller orange mixture than cadmium yellow deep (PY35 (http://www.handprint.com/HP/WCL/watery.html#PY35)) and cadmium scarlet (PR108 (http://www.handprint.com/HP/WCL/waterr.html#PR108)), which have the same hue angles on the color wheel, because the two cadmiums are much more intense paints.

Nevertheless, the same color wheel geometry still applies: the mixture of venetian red and yellow ochre will make a more saturated orange than the mixture of venetian red and chromium oxide green (PG17 (http://www.handprint.com/HP/WCL/waterg.html#PG17)), because hues green and red are farther apart on the color wheel.

color theory

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

This idea of saturation costs is so basic that it was clearly understood in the 18th century, for example as Moses Harris (http://www.handprint.com/HP/WCL/color6.html#harris) explains it (diagram, right):

Any two colours wanting to be mixed, must not be chosen at so great a distance as one third of the [hue] *circle, the nearer they are situated the better; suppose an orange colour is wanted, red and yellow will effect it* [**1**], ... *but red orange and yellow orange mixed will do much better* [**2**], ... *because they are nearer. So with respect to composing a green, blue and yellow will make one* [**3**], ... *but yellow and blue green will make a far brighter colour* [**4**]. *In short if red and blue will not make a fine purple, which every painter knows, it cannot be expected blue and yellow will make a proper green, nor red and yellow a fine orange, as they are not inclined in hue toward each other.* (*The Natural System of Colours,* 1766).

Notice that Harris explains saturation costs without stipulating that two paints are or are not "primary" colors, or that a mixture , or any other artificial rule of artists' color theory. He only talks about the distance between the hues of two colors on the hue circle.

This is the unavoidable, universal **rule of saturation costs** in paint mixing:

the farther apart two colors are on the color circle, and the duller their average chroma, the duller their mixture will be.

Saturation cost means that mixed colors will *always* be less intense than one or both colors they are mixed from. We pay a cost in reduced chroma whenever we create a new color through paint mixtures.

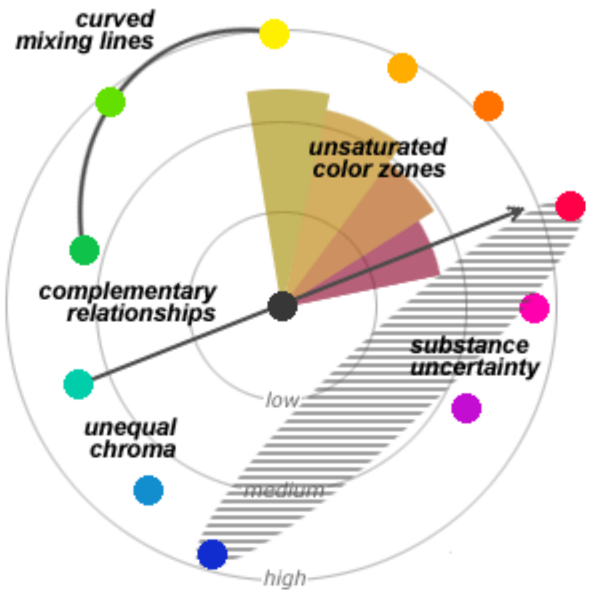
the color wheel fallacy

Newton's color circle was adapted to describe paint mixtures in the early 18th century (http://www.handprint.com/HP/WCL/color6.html#confusions), at a time when the differences between additive and subtractive color mixing were either unknown or only vaguely recognized. However, even after subtractive color mixing was clearly understood, artists still used a color triangle (http://www.handprint.com/HP/WCL/color6.html#sloan) to describe paint mixtures, exactly as Maxwell had done with light mixtures (http://www.handprint.com/HP/WCL/color6.html#maxtriangle).

Unfortunately, the simple color wheel geometry that Newton used to explain saturation costs does not apply to paint mixtures. This problem represents the **color wheel fallacy**: that subtractive color mixtures with paints behave in the same geometrically simple and predictable way as additive color mixtures with lights. Unfortunately they don't, and if we look at the reasons why they don't we can understand why color wheels are relatively poor at predicting paint mixtures.

When Newton devised his hue circle (http://www.handprint.com/HP/WCL/color2.html#newtoncircle) to explain color mixtures, he made the claim that a simple geometrical model could predict the mixing behavior of *spectral lights*. This has turned out to be true, provided that we are not too fussy about the equal brightness (http://www.handprint.com/HP/WCL/color2.html#hkeffect) of the mixtures, and that we define the hue circle as a shape more like a triangle, called a chromaticity diagram (http://www.handprint.com/HP/WCL/color7.html#CIE1976uv).

However, the same approach, using paint locations on a color wheel, fails very badly to explain paint mixtures. This occurs for two reasons: (1) the mixing relationships among different colors of paint are not geometrically simple; and (2) the mixing behavior of a paint is not predicted by its location on a color wheel.

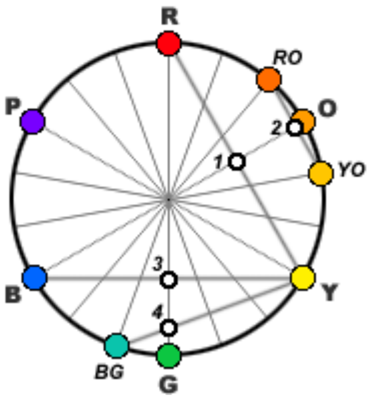


the color mixture problems in a color wheel

The diagram shows the most important problems that arise when attempting to predict subtractive color mixtures with a color wheel.

If we want to explain color mixtures of *light* in terms of a single geometrical figure, they can be very adequately represented by a lopsided triangle with a rounded green corner, called a chromaticity diagram (http://www.handprint.com/HP/WCL/color7.html#CIE1976uv). However there is no geometrical figure that can represent paint mixtures with equal accuracy. In fact, color theory color wheels (http://www.handprint.com/HP/WCL/color13.html) or color triangles (http://www.handprint.com/HP/WCL/color6.html#sloan) are usually drawn as geometrically perfect because a lopsided or quirky geometrical shape would not be any more accurate.

In both monochromatic (single wavelength) lights and in artists' pigments, there is wide variation in apparent saturation or chroma across different hues. A chromaticity diagram represents this fact through its irregular shape, and by shifting the white point (http://www.handprint.com/HP/WCL/color6.html#CIELUV) or point of neutral mixture away from the center of the triangle and closer to the green edge of the chromaticity space. In a color wheel or color triangle, this is represented by shifting the location of paints toward the center of circle, while keeping the achromatic point (white or gray) at the center. But the problem is that **paint chroma changes as paints are diluted**, changing their mixing relationships. Lights in contrast can be made brighter or dimmer without altering the color of their mixtures.



hue locations on the moses harris color wheel

R red; **O** orange; **Y** yellow;
G green; **B** blue; **RO** red orange; **YO** yellow orange; **BG** blue green

The mixture of two lights in a chromaticity triangle will always lie on a straight line (http://www.handprint.com/HP/WCL/color1.html#imaginarycolor) between their points. In contrast, as we will see on a later page, paint mixing lines are erratic (http://www.handprint.com/HP/WCL/color15.html#mixlines) rather than straight in a color wheel. Typically green mixing lines are curved outward, and if magenta and yellow are placed one third of the circumference apart, as is commonly done, then mixing lines between them are curved as well.

We might try to remedy this mixing line problem by spacing the hues around the hue circle so that all mixing lines are approximately straight (for example, by putting blue and yellow closer together). But this only creates new problems. Most important, making the mixing lines straight in one part of the color wheel only makes them curved (http://www.handprint.com/HP/WCL/tech34.html#mixfix) somewhere else. And any respacing will destroy the complementary color relationships (http://www.handprint.com/HP/WCL/color13.html#compprobs) on opposite sides of the color wheel.

If we forge ahead anyway, and find the hue spacing that produces the best compromise in terms of straight mixing lines and complementary color relationships, then we discover that the same "colors" of paint will mix very differently with other colors around the color wheel: the hue of a paint doesn't reliably predict the color of its mixtures. Two paints of the same hue can create very different mixtures with other paints, a problem I call substance uncertainty (http://www.handprint.com/HP/WCL/color5.html#subprobs). This is most obvious when we try to find the mixing complement of each paint (http://www.handprint.com/HP/WCL/color5.html#mixtogray): the same paint can mix a pure gray with very different hues on the color wheel. Paints can only be given a "fuzzy" location on the color circle, because this location changes depending on the other paints we choose to mix with it. In contrast, two monochromatic lights with the same hue will always produce identical color mixtures with every other hue on the chromaticity diagram.

Finally, mixtures of spectral hues (including red violet and purple) always create the appearance of other spectral hues, though these mixed lights can appear whitened or pale: mixing a green light with a red light creates a whitened yellow or orange. In contrast, paint mixtures within the magenta to yellow part of the color wheel seem to create entirely new colors not in the spectrum tans, browns or maroons that define unsaturated color zones (http://www.handprint.com/HP/WCL/color12.html#unzones). Thus, a mixture of cadmium red and chromium oxide green is actually a very dull red orange, but we see and describe the hue as a dark brown. This effect only occurs in one part of the color wheel, which again shows that paint mixtures are not geometrically consistent.

All these problems make it **impossible to "predict" subtractive color mixtures with a color wheel**. Normally, color theory simply ignores these issues in pursuit of geometrical purity and mixing rule simplicity, but the inconsistencies are clearly visible in the paint mixtures and create a great deal of confusion for painting students.

The complexity of subtractive mixtures in particular make all color wheels unreliable predictors of paint mixtures. And any attempt to make them geometrically consistent (as for example in Stephen Quiller's (http://www.handprint.com/HP/WCL/book3.html#quiller2) mixing color wheel, or my artist's color wheel (http://www.handprint.com/HP/WCL /cwheel06.html)) will be half measures at best.

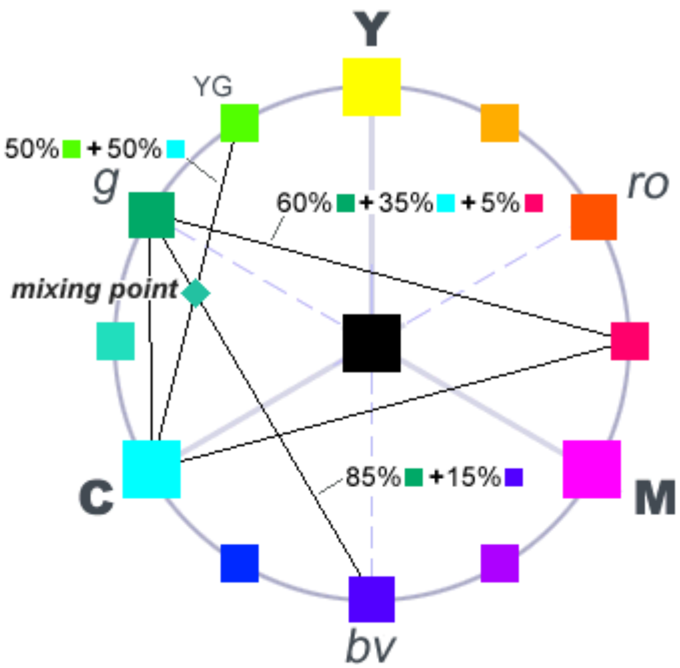
basic mixing method

The solution to the color wheel fallacy is not to throw away the color wheel, but to use it as a rough guide as **a compass to color improvisation**.

It's really very simple: let the color wheel help you choose the mixing paints and approximate paint proportions you need ... then rely on your eye (and your color mixing intuitions) to get the mixture just right.

Now let's use the color wheel to plan and guide a color mixture. This section describes the concepts behind color mixing: the physical methods for paint mixing are discused in the page on working with paints (http://www.handprint.com/HP/WCL/tech14.html#mixing).

This tutorial is *more detailed and explicit* than the intuitive procedure you will learn to use: conscious planning and alternative paint choices will eventually be replaced by your habitual palette and mixing experience. As this happens, your ability to improvise and "go with the flow" will increase as well.



planning color mixtures on a color wheel

The diagram shows how to decide on the best color mixture to obtain a mid valued, somewhat dull bluish green color (indicated as the **mixing point**). It is sometimes possible to mix a color using only two paints, but it is **always possible to mix a color using three paints** provided you choose the right ones.

The hidden difficulty in color mixing is not getting the right proportions of paint in the mixture, it's *choosing the right paints to start with*. So **paint selection is the first step** in improvising that blue green color mixture:

Locate the color you want to mix on the artist's color wheel (http://www.handprint.com/HP/WCL/cwheel06.html). You must first identify the approximate hue (http://www.handprint.com/HP/WCL/color3.html#colormakinghue) you want as a point on the circumference of the wheel; then identify the chroma (http://www.handprint.com/HP/WCL

/color3.html#colormakingchroma) of the mixture by shifting the point toward the center (black) of the wheel, and finally identify the value (http://www.handprint.com/HP/WCL/color3.html#colormakingvalue) (lightness) you want. (Keep in mind that watercolors, especially intense or dark valued colors, lose saturation and lightness (http://www.handprint.com /HP/WCL/cds.html) as they dry.) This is your **mixing point**.

Identify any **mixing lines** that pass through or near this mixing point from any pair of paints available on your palette. (Two lines between different pairs of paints are shown in the figure.)

Identify all combinations of three paints that enclose the mixing point in a **mixing triangle**. (A single triangle shown in the figure.) This is usually a mixing pair that comes pretty close to the right color, plus a third, complementary color (opposite from the color you want) to pull the color toward gray or toward a darker value.

Think about the value, transparency, texture or other handling characteristics desired of the mixture. For example, will two paints mix a color that is dark enough? Will the mixture be too saturated, or not saturated enough? Will the mixture have the right texture, transparency, or staining characteristics? After considering all these issues, **choose the mixing pair** or mixing triad that will give you the attributes you want.

In the example, mixing phthalocyanine green BS (PG7 (http://www.handprint.com/HP/WCL/waterg.html#PG7)) with ultramarine blue (PB29 (http://www.handprint.com/HP/WCL/waterb.html#PB29)) will produce a darker blue green than mixing permanent green light with phthalocyanine cyan (PB17 (http://www.handprint.com/HP/WCL /waterb.html#PB17)) or manganese blue (PB33 (http://www.handprint.com /HP/WCL/waterb.html#PB33)). The manganese blue mixture will be lighter, but have an interesting, granular texture with patches of light green. The mixture with ultramarine blue will have a slight flocculating texture and will be slightly less staining than the mixture of the phthalos green and cyan. The point is that you can choose different combinations of paints in order to get the paint behavior you want in the mixture, or the visual effect you want in the finished color. **Color mixing lets you to choose the material attributes of paints as well as paint color**.

Use the location of the mixing point along the line to **estimate the approximate proportion** of the two paints in the mixture, assuming the two paints are of equal mixing strength. This is important to estimate the amount of paint you need to mix (for example, in a wash).

The relative proportion of paint required depends on several paint attributes, .

Start with the weaker paint (the paint with less tinting strength, weaker concentration, lighter value, or more transparency), and mix it with water to give the desired concentration of paint, in a sufficient volume of liquid to cover the *total color area* you want to paint. (Starting the mixture with enough liquid to cover the total area prevents you from mixing too little paint, especially for a wash.)

Now improvise. **Add the dominant paint very gradually**, from a mere touch of color up to the proportions you estimate will create the desired hue. Observe the mixture carefully, and stop when the hue is close to correct.

Test the mixture on a piece of paper; a mixture on the palette will not look the same on paper. Nearly all paints present a drying shift (http://www.handprint.com/HP/WCL/cds.html) between the wet and dry color, so if accuracy is important, let the test patch dry for 10 minutes before committing the mixture to the painting. Observing the direction of color changes as the mixture dries can also help you adjust the mixture accurately.

If the color is the incorrect hue, adjust toward the exact hue required by adding one or the other (but not both) of the mixing colors. Add water as needed to return to the correct concentration.

If the color is too intense, or if you are mixing with three paints, **add the third (complementary) color** (in very small amounts) to make final adjustments to the saturation or value of the mixture. This can also work to make a final adjustment to the hue.

As mentioned above, typically *one paint will be dominant* in an equal mixture of two paints. So you need to **know the relative mixing strength** of your paints, for each pigment and brand of paint you use, in order to improvise confidently. This is something you pick up with experience, but a few paint attributes can help you anticipate how much one paint will dominate another:

1. **Concentration**. Obviously, the paint that is more concentrated (less diluted with water) will be the dominant or stronger paint in a mixture. The paint concentration depends not only on the amount of water you add to the mixture, but also on the proportion of pigment to vehicle (http://www.handprint.com /HP/WCL/pigmt1.html#pigmentratio) that the manufacturer puts in the paint. (This is noticeable when comparing different brands of the same single pigment paint, especially the strongly tinting phthalocyanines, quinacridones and dioxazine violet.)

2. **Tinting strength**. The dominant paint will have a higher tinting strength (http://www.handprint.com/HP/WCL/pigmt3.html#tinting). Phthalocyanine blue has a tinting strength 40 times greater than ultramarine blue, which means that phthalocyanine blue is much more powerful than ultramarine blue in producing a noticeable color change in a mixture. Manufacturers attempt to

minimize these differences by increasing the amount of pigment in ultramarine blue, and/or by adding fillers to phthalocyanine blue but these workarounds only reduce the clarity and depth of the color.

3. **Value**. Darker valued paints (http://www.handprint.com/HP/WCL/vwheel.html) usually dominate a mixture. When two paints of equal mixing strength are mixed in equal proportions, the mixed color will lean toward the darker paint. This has less to do with paints than with the eye: equal lightness changes are more noticeable in light valued colors than in dark ones. Darker colors must be added carefully to a mixture, and it is more difficult to alter a mixture by adding a lighter color.

4. **Color Temperature**. Warm colors (http://www.handprint.com/HP/WCL/color12.html#warmcircle) tend to dominate a mixture, especially hues from magenta through orange. This occurs partly because modern warm colors are almost entirely synthetic organic pigments (which have a high tinting strength), and partly because warm hues have a higher chroma (are more intense) than cool hues.

5. **Opacity**. Opaque pigments (http://www.handprint.com/HP/WCL/palette2.html#opaque) tend to dominate over "transparent" pigments in a mixture, simply because opaque pigments are more concentrated (http://www.handprint.com/HP/WCL/tech16.html#opacity). The transparent pigment shows an opaque pigment behind it, but the opaque pigment covers the transparent pigment underneath.

These are only guidelines: experience must teach you how much of a paint to use in mixtures with other paints. You will also learn to adjust differences in value, opacity or tinting strength by how much you dilute paints (http://www.handprint.com/HP/WCL/tech16.html) out of the tube. But the principal and safest rule is always this: **only add a small quantity of dominant**

paint to the weaker paint, and increase the dominant paint slowly until you get the exact color you want.

All these issues are simplified when using a consistent and limited palette, so you can learn the distinctive mixing proportions for every pair of paints.

The range of effects you can get from your mixing combinations depends on your choice of paints. More variety is possible if you select both organic and inorganic pigments (http://www.handprint.com/HP/WCL/pigmt1.html#pigments) from both the warm and cool side of the color wheel, and include a few earth, granulating and opaque pigments as well. The basic palette (http://www.handprint.com/HP/WCL/palette5.html) discusses some of these alternatives.

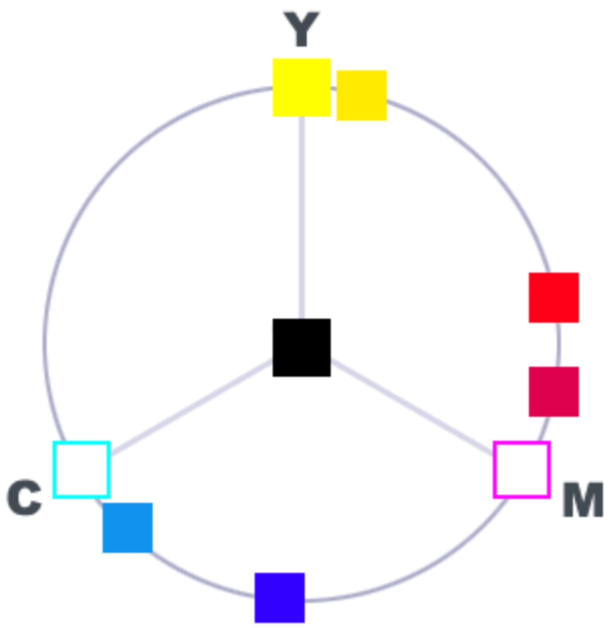
However, the more paints you select for your palette, the harder it is to learn all their combinations. In a 6 color palette there are only 15 possible mixing pairs; in a 12 color palette there are 66; in an 18 color palette there are 153! You will master color mixing more quickly if you start with fewer paints in your palette.

split primary palette

Color mixing strategies inevitably leads to the issue of special paint selections or palette designs (http://www.handprint.com/HP/WCL/paletfs.html) intended to make color mixing simpler, more effective or downright foolproof (http://www.handprint.com/HP/WCL/book3.html#wilcox). Perhaps the most popular among these is the split primary palette (http://www.handprint.com /HP/WCL/palette4r.html).

The Dogma. If the artist limits his paint selection to the traditional primary triad palette (http://www.handprint.com/HP/WCL/palette4c.html), then the saturation costs in secondary color (http://www.handprint.com/HP/WCL/color13.html#secondary) mixtures (orange, purple and green) are so severe (http://www.handprint.com/HP/WCL/color13.html#mixcool) that even some artists committed to their primary color dogma look for a way to reduce them.

The common remedy has been to **split each "primary" color into a pair of colors**, each leaning toward one of the other two "primaries." So the single primary yellow paint is replaced by two paints: a warm (deep) yellow that "leans toward" (is tinted by) the red "primary," and a cool (light) yellow that leans toward blue. Similar replacements are made for the other two "primaries," which doubles the palette from three to six paints.



the split primary palette

the version proposed by Nita Leland

According to Nita Leland (http://www.handprint.com/HP/WCL/book3.html#leland), a representative split primary palette would consist of:

cool yellow : cadmium lemon (PY35 (http://www.handprint.com/HP/WCL/watery.html#PY35)) or benzimidazolone lemon (PY175 (http://www.handprint.com/HP/WCL/watery.html#PY175)) *(leans toward blue)*

warm yellow : cadmium yellow (PY35 (http://www.handprint.com/HP/WCL/watery.html#PY35)) or nickel dioxine yellow (PY153 (http://www.handprint.com/HP/WCL/watery.html#PY153)) *(leans toward red)*

warm red : cadmium scarlet (PR108 (http://www.handprint.com/HP/WCL/waterr.html#PR108)) or
pyrrole red (PR254 (http://www.handprint.com/HP/WCL/waterr.html#PR254)) *(leans toward yellow)*

cool red : quinacridone carmine (PR N/A (http://www.handprint.com/HP/WCL/waterc.html#PR%20N/A)) or quinacridone rose (PV19 (http://www.handprint.com/HP/WCL/waterc.html#PV19R)) *(leans toward blue)*

warm blue : ultramarine blue (PB29 (http://www.handprint.com/HP/WCL/waterb.html#PB29)) *(leans toward red)*

cool blue : phthalocyanine blue GS (PB15:3 (http://www.handprint.com/HP/WCL/waterb.html#PB15)) *(leans toward yellow)*

The color theory logic for these substitutions goes like this: a yellow that leans toward blue is *a yellow that actually contains blue,* and a blue that leans towards yellow is a blue that contains yellow. So the blue and yellow reinforce each other when mixed to make green. But if either color leans toward red, then red is carried into the mixture through the yellow or blue paints. This isn't good, because mixing all three primaries creates gray or black (http://www.handprint.com/HP/WCL/color5.html#black), and this dulls the remaining green mixture.

This becomes a rule: when mixing two primary colors, choose the paints that lean toward each other to get the most vibrant mixture. The slogan is, *"never put the mixing line across a 'primary' color"* that is, don't choose either two primaries leaning toward or tinted with the third primary, because mixtures containing all three primaries mix to gray. Split primary advocates call these mixtures "mud."

Of course, the painter can intentionally choose one or both of the primaries leaning toward the third primary, if he wants less intense or near neutral mixtures. But then color theory painters will call his paintings mud.

The Critique. Where did these muddled recommendations come from? Straight out of the Newtonian color confusions (http://www.handprint.com/HP/WCL/color6.html#confusions) of the 18th century. Essentially the same color concepts appear in the color wheel text by Moses Harris (http://www.handprint.com/HP/WCL/color6.html#harris), and are accepted without serious challenge in Michel-Eugène Chevreul's The Principles of Color Harmony and Contrast (http://www.handprint.com/HP/WCL/book3.html#chevreul) (1839). Chevreul describes color mixing beliefs that must have been widely accepted by artists of his time; one passage is worth quoting at length:

We know of no substance [pigment or dye] *that represents a primary color that is, that reflects only one kind of colored light, whether pure red, blue or yellow. ... As pure colored materials do not exist, how can one say that violet, green and orange are composed of two simple colors mixed in equal proportions? ... Instead we discover that most of the red, blue or yellow colored substances we know of, when mixed with each other, produce violets, greens and oranges of an inferior intensity and clarity to those pure violet, green or orange colored materials found in nature. They* [the authors of color mixing systems] *could explain this if they admitted that the colored materials mixed together reflect at least two kinds of colored light* [that is, two of the three primary colors], *and if they agreed with painters and dyers that a mixture of materials* *which separately reflect red, yellow and blue will produce some quantity of black, which dulls the intensity of the mixture. It is also certain that the violets, greens and oranges resulting from a mixture of colored materials are much more intense when the colors of these materials are more similar in hue. For example: when we mix blue and red to form violet, the result will be better if we take a red tinted with blue, and a blue tinted with red, rather than a red or blue leaning toward yellow; in the same way, a blue tinted with green, mixed with a yellow tinted with blue, will yield a purer green than if red were part of either color*. [1839, ¶¶157-158; my translation]

There you have the color ideas behind the split primary palette. Unfortunately, most of them are factually wrong or logically unrelated.

Chevreul is criticizing the idea that "primary" colors can be represented in paints by observing that these primary paints can't mix all the hues of nature with sufficient intensity or chroma. From that he concludes that paint pigments do not reflect "only one kind of light". A yellow primary paint must reflect "yellow" light mixed with some "blue" or "red" light, which dulls the pure yellow color. As we can't avoid this color pollution, we minimize it by mixing colors tinted with each other so the thinking goes.

However, paint colors do not simply represent spectral "colors" as Chevreul believed: a primary yellow paint does not just reflect a lot of "yellow" light. Nor is color "in the light" as *colored light;* there are no "magenta," "red violet" or "purple" wavelengths in the spectrum, so those colors cannot be "in" the light. The same surface colors can result from very different light mixtures (http://www.handprint.com/HP/WCL/color5.html#subprobs): yellow results from a "red" and "green" mixture, and red violet from a "blue violet" and "red" mixture. These confusions were clarified later in the 19th century through the popularizing science books by Hermann von Helmholtz (http://www.handprint.com/HP/WCL/color6.html#helmholtz) and Ogden Rood (http://www.handprint.com/HP/WCL/book3.html#rood). Surprising, then, that the "paint color equals light color" fallacy is still widely believed by painters today Michael Wilcox (http://www.handprint.com/HP/WCL/book3.html#wilcox) teaches it as the basis of his color mixing system.

In addition, you can *never* find a paint, a crystal or a light whose color is "pure enough" to match a primary color. This is because primary colors are *always* imaginary or imperfect (http://www.handprint.com/HP/WCL/color6.html#imaginary): they can never be matched by visible lights or paints, and visible lights or paints can never mix all possible colors. The reason for this lies in the design of our eye in the overlapping response curves (http://www.handprint.com/HP/WCL/color1.html#logconesens) of the **L**, **M** and **S** light receptors. The "impurity" of the light reflected by the paint certainly aggravates the problem, but is not the cause of it. The "color theorist" dogma that paint mixing problems arise because paints are "impure colors" is bogus.

Choosing two paints or inks that are more similar in hue *does* increase the intensity of their mixture, as Chevreul says. But these again have nothing to do with the contamination of one primary color with another. They appear even when we mix monochromatic (single wavelength) lights that are completely free of tint by any other hue. In fact, mixing pure spectral lights was how Newton discovered (http://www.handprint.com/HP/WCL/color2.html#extraspectral) saturation costs in the first place!

In brief, the split primary palette is based on 19th century color ideas that have nothing to do with the facts of color perception and color mixing as we understand them today.

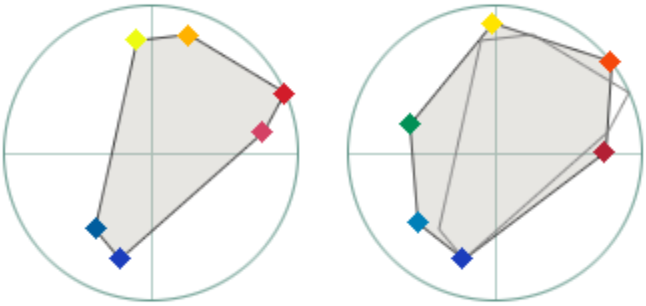
The Demonstration. But the pragmatist may say: who cares? Just because the justification is murky doesn't mean that the split primary palette isn't an effective selection of paints.

Fair enough. So let's hold the split primary palette to its two key claims: (1) that red and blue (rather than magenta and cyan) are the most effective primary colors; and (2) that splitting these primary colors allows us to mix the most vibrant secondary colors (orange, purple and green). It's easy to show that both these claims are false.

A "pure" red or blue makes an ineffective primary color because these colors fail the basic requirement (http://www.handprint.com/HP/WCL/color5.html#2stim) for a subtractive primary paint: it must *strongly stimulate two receptor cones but not the third*. A pure red and pure blue paint mix dark, grayed purples, for example, because they have almost no reflectance in common (http://www.handprint.com/HP/WCL/color3.html#mixprofile); for the same reason, the blue and yellow make very dull greens. So the split primary palette *starts out* with an inaccurate definition of the primary paints (http://www.handprint.com/HP/WCL/color13.html#primary) most useful for subtractive color mixtures.

We can evaluate the second, "vibrant color" justification for the split primary palette by comparing it to any other palette of six paints, for example the secondary palette (http://www.handprint.com/HP/WCL/palette4e.html), to see which paint selection is superior. There are two ways to do this.

A simple "back of the envelope" approach is to print out a copy of the pigment map presented on the CIECAM $a_C b_C$ plane (http://www.handprint.com/HP/WCL/camwheel.html), identify on this map the location of the pigments used in all paints in the palette (use the complete palette (http://www.handprint.com/HP/WCL/palette1.html) to identify specific pigments), then connect these pigment markers to form the largest possible, straight sided enclosure (see examples below). The closed area is the gamut (http://www.handprint.com/HP/WCL/color13.html#gamut) of the palette the approximate range of hue and saturation that it is possible to mix with that selection of paints. The palette with the larger gamut will create a wider range of color mixtures.



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

comparing the gamut of two palettes

split primary palette (left) and secondary palette (right)
on CIECAM $a_C b_C$ plane

The split primary palette (http://www.handprint.com/HP/WCL/palette4r.html) (at left) creates a narrow lozenge of color mixtures that is skewed toward the "warm" colors of the palette, and puts the heaviest saturation costs (dull mixtures) in the mixed greens and violets. In contrast, with the equally spaced secondary palette (http://www.handprint.com/HP/WCL/palette4e.html) (at right), we get a substantially increased range in color mixtures. This is because a single intense pigment anchors each primary and secondary hue, which pushes back the limits of the color space as far as possible (particularly on the green side). Same number of paints, very different gamuts.

The alternative (and better) way to compare palettes is to use each one to mix the twelve colors of a tertiary color wheel (http://www.handprint.com/HP/WCL/color13.html#tertiary). Display these mixtures either side by side or as matching paint wheels (http://www.handprint.com/HP/WCL/tech15.html) (below), and see what you get.

comparing paint wheels made with two palettes

split primary palette (left) and secondary palette (right)

This side by side comparison confirms the gamut differences identified with the palette schemes. The mixed red orange in the split primary palette (left) is so dull it is close to brown; the purple is dark and grayish, and the mixed greens are drab across the entire range. In contrast, the secondary palette (at right) is obviously much brighter in the greens, produces a more evenly saturated range of warm hues, and gets juicy purples as well. If you don't want "mud," then the split primary palette is not the one to choose!

Can we fix these problems by changing the selection of split primary paints? Yes we can, and the solutions people choose are revealing. The palette scheme for the Wilcox **six principle** [he means *principal*] **colors** shows that his split primaries have turned into the secondary color wheel (http://www.handprint.com/HP/WCL/color13.html#secondary), but with green omitted in order to provide two very similar yellows.

(http://www.handprint.com/HP/WCL/colormap.html) palette scheme for the Wilcox six principal colors

from "Blue and Yellow Don't Make Green" (http://www.handprint.com/HP/WCL/book3.html#wilcox) (2001)

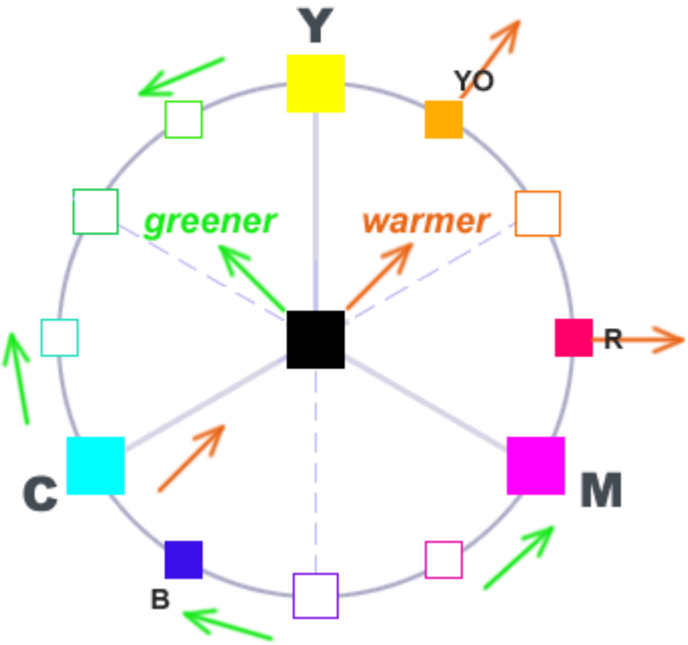
Wilcox has widened the split between the red and blue primaries to the point where they are completely different hues (scarlet and magenta, or blue violet and green blue) yet he still hangs onto his two similar "primary" yellows. This is a funny and revealing example of how a color dogma accepted without question (you *must* use primary colors!) can trample on color mixing common sense (hey, mixtures look so much brighter if you add a scarlet, blue violet and green paint!).

Not only have we found that the split primary palette fails to meet its claims, and its color theory justifications are inaccurate, I've proven by demonstration and explanation that **the secondary palette is the superior mixing system**. And because it lets the painter choose many different paints for the three contrasting pairs of complementary pigments, the secondary palette offers the largest gamut and value range, and the greatest alternative choices of transparency, staining, granulation, texture, and handling attributes in paints that are possible with a six paint palette. Try it for yourself and see.

unequal color spacing

The logic of the split primary palette contains the germ of an important idea: that you can explicitly control the saturation costs of your color mixtures by *the grouping or spacing* of the most saturated paints in your palette.

Increasing the color wheel or hue circle distance between two paints increases the or dullness in their midpoint mixtures, and within the "primary" triad (http://www.handprint.com/HP/WCL/palette4c.html) or split "primary" (http://www.handprint.com/HP/WCL/palette4r.html) frameworks this effect is most pronounced in orange, purple and green colors. By manipulating the bright or dull mixing potential of these purples and greens, the artist can shape the fundamental color dynamics of his painting palette (http://www.handprint.com/HP/WCL/paletfs.html).



unequally spaced colors and the implied illuminant

The color wheel schematic (above) shows the two main variations painters are likely to use: when the illuminant (http://www.handprint.com/HP/WCL/color1.html#dayphases) the *color of light* shifts warmer (http://www.handprint.com/HP/WCL/color12.html#colorlight) (toward longer wavelengths, becoming yellowish or reddish) or greener (http://www.handprint.com/HP/WCL/color12.html#nogreen) (the color of intense noon sunlight).

The basic principle is that when the illuminant has a distinct color, it **brightens similar hues and dulls complementary hues**.

Warmer Color Shifts. In this case, typical of late afternoon light or artificial light from a candle or incandescent light, warm colors become more saturated and cool colors become darker and duller.

This suggests choosing warm color (red to yellow) paints that have higher saturation and cool color (blue) paints that are relatively darker and duller. Burnt sienna would be replaced by cadmium orange, and phthalocyanine blue by iron [prussian] blue or a red shade of phthalo blue.

Provided the light yellow is not too pale (greenish), all mixed yellows will be very saturated and light valued. If the "cool" red is shifted from a bright quinacridone magenta to quinacridone red, and the "warm" red into red orange, the saturation of mixed warm hues (http://www.handprint.com/HP/WCL/color13.html#mixwarm) will be consistently at maximum saturation.

The greens mixed from yellow and blue will be moderately dull and somewhat dark. These muted greens yield dominance to the more intense reds and oranges, reducing the fundamental visual tension between red and green. Because all the greens must be mixed, they will be more varied and interesting.

The blue paints are typically grouped close together, so the mixed middle blues will be relatively bright, but quickly become muted as they are mixed with the "cool" yellow or red. This gives the range of blues a chromatic emphasis around the sky color, surrounded by a range of less intense green blue and blue violet mixtures for foliage and shadows. The mixed violets will be somewhat dull, and dull dark blues (the visual complements of yellow or red orange), not purples, should be used to tint shadows.

Greener Color Shifts. A "green" color shift is characteristic of colors under intense noon sunlight. Daylight does not appear green to our eyes because of the color balancing effect of chromatic adaptation, but the *relative* color emphasis that results can be modeled by different palette choices.

The main effect of this greening is to brighten greens and to dull purples (because purples are the complementary hue of the light). As there are few useful purple or green pigments, the most common method to produce this bias is to shift the yellow and blue paints toward each other by choosing a lemon or greenish yellow as the "cool" yellow, and a greenish or turquoise blue for the "cool" blue thereby increasing the saturation of green mixtures. The greenish blue should also be somewhat lighter valued, if possible: cobalt turquoise or cobalt teal blue (PG50 (http://www.handprint.com/HP/WCL/waterg.html#PG50)) are very useful alternatives.

In contrast, the hue circle distance between the "cool" red and "warm" blue should be increased, and one of the colors should be dark valued, if feasible for example, by choosing a phthalo blue red shade or a quinacridone carmine. These will produce dull dark purples that are usefil to tint shadows with the complementary hue (http://www.handprint.com/HP/WCL /color12.html#purpleshadow) of the illuminant color.

Other imbalanced distributions are possible, which might contrast a broad range of blues against dull earths, vibrant greens against dull reds, and so on in many combinations. But the palette shown in the figure, with most of the saturation costs in the violets and greens, is one of the most popular; dozens of palettes (http://www.handprint.com/HP/WCL/paletfs.html) are variations on it.

Why not just choose a large number of paints that are very closely spaced all the way around the color wheel? You can, if you want. These colorist palettes (http://www.handprint.com/HP/WCL/palette4t.html) are useful for a bright and lively style of painting that specifically *does not* give the impression of a certain kind of light. The point is that saturation costs can buy you expressive resources, particularly in landscapes and portraits. Forcing some color mixtures to be dull confers a light giving power to the pure colors they are mixed from, which can create a deep color harmony across the value structure of a painting.

N E X T : an artist's color wheel (http://www.handprint.com/HP/WCL/color16.html)

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

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click here (http://www.handprint.com/HP/WCL/mix.html)
for an illustrated version of the mixing procedure