handprint : learning color through paints

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learning color through paints

Any painter with the ability to manage color by mixing paints has an understanding of color. How does the painter gain that understanding? By learning the *color behavior of paints* without the "color theory" intellectual baggage especially the 18th century "primary" color (http://www.handprint.com/HP/WCL/color6.html#materialtrichromacy) baggage that still haunts painters today (http://www.handprint.com/HP/WCL/color14.html#splitprimary).

Knowledge of chemistry is a poor guide to becoming a proficient chef, understanding physics has little to do with building a house, and familiarity with biology does not make a proficient gardener. In the same way, skillful painting relies on practical rather than theoretical or abstract knowledge.

This is not a tutorial in composition and design or in color harmony & contrast (http://www.handprint.com/HP/WCL/tech13.html). It is a complete course in the knowledge of watercolor paints necessary to make paintings with ease and control. The emphasis is on the *craft* of painting rather than the *dogma* of color.

I have watched my own color mixing I mean, *paint mixing* habits, identified areas where paint mixing seemed harder or easier to understand and control, and clarified how I plan a color mixture or color design. This page summarizes what I know.

three guiding principles

In philosophy the distinction is sometimes made between the map and the landscape between a dinky colored image on paper, and the massive physical reality of mountains and valleys. The point of this distinction: our concepts about the world don't do justice to the facts.

The traditional method of teaching painters how to use paints is "top down" it emphasizes the color theory (http://www.handprint.com/HP/WCL/color18.html) map as a way to learn the paint mixing landscape. In my experience, this focuses attention on concepts and language, rather than on tools, procedures, and visible results.

The remedy is to draw the map "bottom up," by first hiking through the landscape that is, by actually using materials and experiencing how they perform in different situations or applications and only then looking for the concepts that describe what you know from experience. This is the first guiding principle: **learn color with your eyes and hands** rather than with your mind.

This sensory, hands on awareness leads you to see that paints do what they do as unique material substances (http://www.handprint.com/HP/WCL/color5.html#subprobs), not as interchangeable "colors". Each paint has a unique personality, and different paints combine in unique ways. The result is called a gamut (http://www.handprint.com/HP/WCL/color13.html#gamut), the range of all possible color mixtures. The gamut *always* depends on the specific choice of paints, inks or dyes, as well as the attributes of the support (paper or other surface) used for the painting. Change the colorants or the support, and the gamut changes too. So the second guiding principle is that **color always depends on materials**: it is not something we understand as an abstraction.

This may seem to make understanding color really complicated, and it does. In fact, the landscape of color is so complex it can never be adequately simplified as a single map. This requires the painter to be alert to what the materials are actually doing, and this leads to the third guiding principle: **paint mixing is always a form of improvisation**. In particular, artists don't "predict" color mixtures with a color wheel (or anything else). They just become better at using familiar materials in new ways. They learn through experience how paints usually work together, but apply these insights to new situations in a spirit of exploration and play.

color theory

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

Although we will start with a specific selection of paints in order to learn how color is created through paint mixture, the goal is to learn how to master paint mixing with any combination of paints using our eyes and hands to learn how things work, keeping in mind the gamut of colors that the paints make available to us, and relying on improvisation to solve problems. No magical qualities, no eternal essences, no special color symbolism are involved just the practical process of choosing and using available paints.

27 color study topics

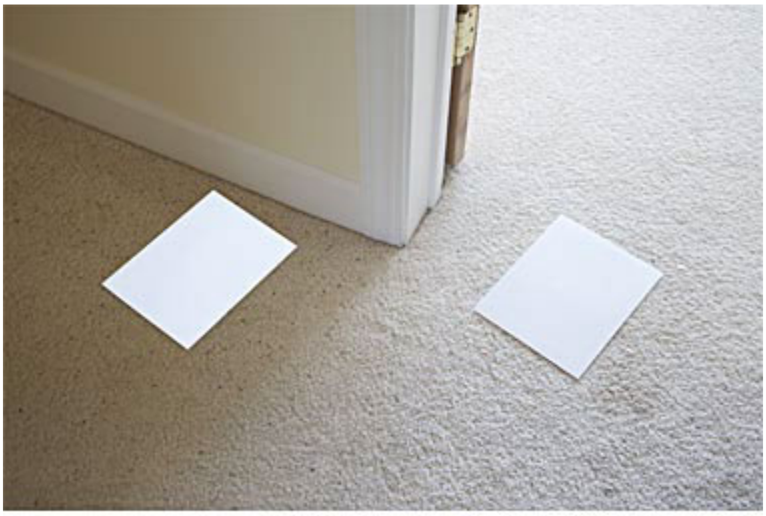
Here are 27 color study topics, arranged in eight sections to highlight the connection between topics. For these lessons to be effective, you the reader must actually do the color mixing exercises, and read carefully to make sure the conclusions I offer actually match your experience. The emphasis is always on *your* skill with paints, and this means all color concepts must be clearly justified by *your* color perceptions and paint mixing experience.

1 Color is a Judgment. Let's start at the beginning: what we mean when we talk about "color".

The essential fact is that **color is in the mind**, not in the external world. Paints have definite physical attributes that produce our color experience, but color experience is remarkably dynamic and adaptive because our *mind* determines what a "color" is, not the physical attributes of the paint.

If only a single color is visible, the color is a **sensation** produced by stimulation to the retina in the eye. If two or more colors are visible at the same time, color is a **perception** that is strongly affected by contrasts in color and brightness. And in everyday experience, color is a **judgment** that is strongly affected by our *interpretation of light and objects in physical space*. This is a profound and essential point: *color* is really a way of interpreting and understanding the effects of *reflectance,* the apparent quantity of light reflected by different surfaces under the same quantity of illumination.

This sounds abstract, so here is a concrete example: three photographs of the same two sheets of paper, one lying in light, the other in shadow.



context in color judgment

The middle photograph is the original. In the top photograph, both sheets are exactly the same color, but the sheet in shadow seems to glow with its own light. In the bottom photograph, both sheets are exactly the same color, but the sheet in light seems to be brown or gray. The only difference between the two sheets is the situation or *context* in which they appear.

Color experience is the outcome of context judgments (http://www.handprint.com/HP/WCL/color4a.html) that combine the quality of light and our understanding of the physical world to create the appearance of constant object colors. The same physical color (such as a layer of paint) can appear to be different colors depending whether we see it in isolation, in combination with one or more other colors, or as the surfaces of objects in space and the lighting under which they viewed; and all these contexts change depending on the *amount of illumination* that we perceive (or assume) is falling on the surface.

2 The Colormaking Attributes. Given the astonishing variability that results from the effect of our contextual judgments of light and reflectance, it is remarkable that just **three attributes adequately describe all color experience**, no matter what kind of viewing situation is involved provided we ignore the material dimensions of color such as surface texture, mottling, iridescence, translucency or gloss. These three attributes are the colormaking attributes (http://www.handprint.com/HP/WCL/color3.html#colormaking) of hue, lightness and chroma.

Hue is the name for any color found within the prismatic light spectrum (http://www.handprint.com/HP/WCL/color1.html#spectrum) (*red, orange, yellow, green, cyan, blue, violet*) or as an extraspectral (http://www.handprint.com /HP/WCL/color2.html#extraspectral) light mixture made by overlapping the opposite ends of two spectra (*purple, magenta*).

Every hue can be diagrammed as a specific location on the circumference of a or color wheel (http://www.handprint.com/HP/WCL/color13.html#createwheel). If we cut this circle between purple and red, it forms a linear hue series similar to the example (below).

color variation in hue only

To standaridize the way we talk about color, hue names are limited to a small number of spectral categories: *red, orange, yellow, green, blue* and *violet*. These are the six fundamental hue categories.

However, in a prismatic spectrum the hues gradually blend from one into another. For this reason, compound names (http://www.handprint.com /HP/WCL/color13.html#names) can be made by joining the names of neighbor or blended spectral hues (*blue red, yellow green, green blue*) or by joining a spectral name with a color qualifier (*light yellow, warm red, middle green*).

Lightness is the light or dark quality of a surface color relative to a pure "white" surface, which is the visual benchmark for how much light is falling on all surfaces under the same illumination for example, all the objects in a landscape under the sun, or all the objects in an office under ceiling lights. (If the color appears to be a light then we make judgments of *brightness* or luminance (http://www.handprint.com/HP/WCL/color3.html#luminance) in relation to the average light or dark to which our eyes have become adapted.) The example (below) shows variations in lightness from *dark* to *light*.

color variation in lightness only

Painters often call lightness the *value* of a color, following the 19th century terminology adopted by the Munsell Color System (http://www.handprint.com/HP/WCL/color7.html#MUNSELL).

Hue purity is amount of "pure hue" visible in the color in comparison to the amount of white, gray or black that appears in the color; painters sometimes call this the *intensity* of a color. It turns out that "pure hue" is rather difficult to define (http://www.handprint.com/HP/WCL/color3.html#colormakingchroma), but it corresponds to the intensity of hues that appears in a prismatic spectrum. Colors that contain no hue, and therefore appear white, gray or black, are *neutral* or *achromatic*. The example (below) shows the variation from a pure neutral to an intense red.

color variation in hue purity (saturation) only

The technical term for hue purity (for example, in the Munsell Color System) is **chroma**, and the common visual judgment is **saturation**, which is the amount of chroma in a color relative to its lightness (in surface colors) or brightness (in lights).

The colors of physical surfaces which always absorb some of the light falling on them, and reflect the rest appear to contain some quantity of white or black, and therefore all surface colors (including paints) appear less saturated than spectral lights, or transmitting materials such as stained glass.

These three terms allow for accurate, unambiguous communication about color. Whenever possible, avoid impressionistic or metaphorical color descriptions such as *dingy*, *luminous*, *rich*, *bold*, *subdued* or *brilliant* (unless you want to be impressionistic and metaphorical).

There are **four perceptual color constants** that govern our experience of the colormaking attributes. Every painter should know these by heart:

1. Surface colors always appear as the subtractive mixture (http://www.handprint.com/HP/WCL/color10.html#surfaceshadow) of the object color with the color of the light illuminating the surface (although the effects of subtle illumination color are usually removed from color experience by chromatic adaptation (http://www.handprint.com/HP/WCL/color4.html#chromaadapt)).

2. Saturation is constant across the illuminated and shadow sides of an object (the chroma of the color is reduced in proportion to the lightness, so the apparent saturation of surfaces is the same when they are brightly illuminated or when they are shadowed).

3. Within the range of natural light variations, increased illumination increases both lightness contrast and chroma contrast across surfaces of different colors, and also increases our ability to discriminate between two very similar hues.

4. Surfaces that are much brighter than the contextual pure "white" surface appear to be lights or to be "shining" like a light.

3 The Paintmaking Attributes. To emphasize the difference between color perceptions and material paints, the painter should learn the many physical attributes of paints that are important to painters.

First among these is the **pigment content**, which includes the *type* and *quantity* of pigment used.

The pigments used in modern art materials are industrially manufactured, and are either strongly colored mineral crystals (inorganic pigments) or carbon based dye molecules fused to the surface of transparent mineral crystals (organic pigments).

These industrial pigment products are identified by a generic alphanumeric code known as the color index name (http://www.handprint.com/HP/WCL/pigmt6.html#ciname). The CI naming system is administered primarily by the Society of Dyers and Colourists (UK), but pigment manufacturers may assign these CI names to their pigment products according to their own criteria. For example, many assign the CI names for naturally occurring iron oxides (PBr7 or PY43) to synthetic iron oxide pigments (PR101 or PY42) such as those used in wood and leather stains. The CI naming system is valuable but not infallible.

All references to specific pigments in this page include the pigment's generic color index name, which is a link to the pigment information in the guide to watercolor pigments (http://www.handprint.com/HP/WCL/waterfs.html). In the United States, voluntary industry standards require watercolor paint manufacturers to print the CI name of pigment ingredients on the paint packaging and in paint color charts or technical information. *Do not purchase paints from manufacturers who do not provide this disclosure*.

The quantity of pigment in the paint, as a proportion of the total volume of paint, is the pigment load (http://www.handprint.com/HP/WCL/pigmt1.html#pigmentratio), which is equivalent to the tinting strength (http://www.handprint.com/HP/WCL/pigmt3.html#tinting) of the paint in comparison to other paints that use the same type of pigment. (Each type of pigment also has its characteristic tinting strength, but this is diluted by the paint vehicle.)

The type of pigment and pigment load also determine the lightfastness (http://www.handprint.com/HP/WCL/pigmt9.html) of the paint, or its permanence under long light exposure; the paint hiding power (http://www.handprint.com/HP/WCL/pigmt3.html#refractiveindex) (which watercolorists traditionally call *transparency*), the pigment particle size (http://www.handprint.com/HP/WCL/pigmt3.html#particlesize) (which watercolorists call *granulation* when the particles are large and *sedimentation* when the particles are small and the pigment particles are heavy in water), and the paint's staining (http://www.handprint.com/HP/WCL/pigmt3.html#staining) behavior on paper.

All these attributes contribute to the **color appearance** attributes of the paint, which are described by the colormaking attributes defined in the previous topic.

These paint attributes are : the immediate point is that paints have many *material* attributes that color sensations do not.

4 The Hue Circle. Colors exist in the mind and are dependent on the way our eye and nerves work together, but colors are also shaped by the physical behavior of light in relation to surfaces. So colors are related to each other, both logically (in the way the mind works) and holistically (in the way the world works).

The traditional way to diagram these color relationships is with a **hue circle**. The hue circle was conceived in the 18th century by Isaac Newton (http://www.handprint.com/HP/WCL/color2.html#newtoncircle), and it remains the most useful way to summarize and think about color relationships.

To reduce clutter, it is convenient to represent only a small number of **hue categories** around a hue circle (diagram, right). In a six hue or secondary hue circle (http://www.handprint.com/HP/WCL/color13.html#secondary), these representative hues (in clockwise order from the top) are yellow, orange, magenta, violet cyan and green. There is a seventh color at the center, not a hue but a dark neutral that results from mixing all the hues together.

These hue names have a specific meaning that differs somewhat from common usage:

yellow (**Y**) means a light value, saturated yellow (http://www.handprint.com/HP/WCL/palette1.html#yellow) that does not appear to have any red or green tint.

orange (**O**) means a middle value, saturated red orange (http://www.handprint.com/HP/WCL/palette1.html#redorange) similar to a scarlet or vermillion.

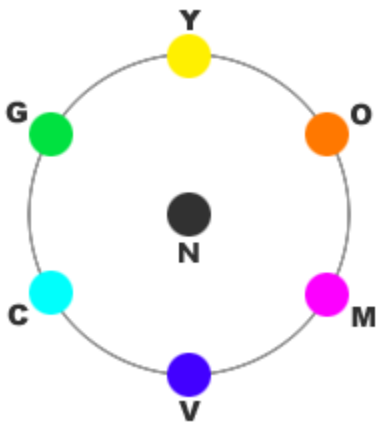
magenta (**M**) means a middle value, saturated violet red (http://www.handprint.com/HP/WCL/palette1.html#violetred) with a hue midway between spectrum red (http://www.handprint.com/HP/WCL/IMG/RC/red.html) and purple.

violet (**V**) means a dark value, saturated violet blue (http://www.handprint.com/HP/WCL/palette1.html#violetblue) that is midway between blue and purple.

cyan (**C**) means a middle value, saturated green blue (http://www.handprint.com/HP/WCL/palette1.html#greenblue) similar to a pure turquoise.

green (**G**) means a middle value, saturated green (http://www.handprint.com/HP/WCL/palette1.html#green) that does not appear to have any blue or yellow tint.

Note that each hue category refers to a saturated rather than a dull color: umbers, browns, pastels and grayed colors are excluded from a hue circle. That is, lightness and hue purity are not necessary to describe the logical and holistic relationships among *hues*.



an ideal secondary hue circle

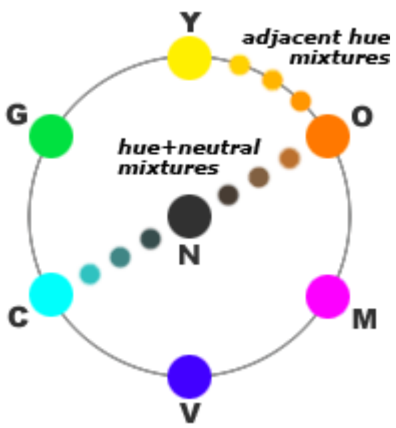
a neatly arranged hue circle shows ideal relationships among abstract color concepts; it only roughly describes the actual relationships among visual colors or colors of paint

These six hue categories divide the hue circle into six roughly equal sections. They are useful hue markers because it is obvious to most people where other hues belong blue goes between violet and cyan, turquoise goes between cyan and green, red goes between magenta and orange, and purple between magenta and violet.

A hue circle is only a kind of illustration of the *logical* relationships among hue categories or *color concepts*. Colors of light mixtures cannot be "predicted" with a hue circle: this can only be done with a technical color map called a chromaticity diagram (http://www.handprint.com/HP/WCL/color6.html#CIE1964).

And, as explained below, a hue cicle (or "color circle" or "color wheel") cannot describe the *color mixtures* among actual colors of paint. In fact, the colors of paint mixtures cannot be predicted by *any* diagram. Taking color wheels (http://www.handprint.com/HP/WCL/color13.html) or color triangles (http://www.handprint.com/HP/WCL/color6.html#sloan) as literal guides to paint mixing only gets in the way of understanding how color actually happens through paint mixtures.

A delightfully compact and elegantly designed color tutorial based on the secondary or six color palette is available as Ordering Colors, Playing with Colors (http://www.amazon.com/gp/product/3721204557/) by Moritz Zwimpfer (School of Design Basel/Verlag Niggli, 2002).



mixtures in an ideal hue circle

the hue circle locates all other hues as mixtures of two neighbor hues on the circle, and locates all shades of a hue as mixtures of the hue with a neutral

5 Tradeoffs in Paint Selection. The hue circle represents a closed band of colors that shade continuously one into another. All hues are equal. How do we select from this infinite diversity of hues the minimum number of "colors" necessary to make an effective painting?

The answer proposed by 18th century artists (http://www.handprint.com

/HP/WCL/palette4r.html) and "color theorists" was to choose "primary" colors (http://www.handprint.com/HP/WCL/color6.html) of paints. These colors were defined using three criteria: (1) each "primary" color cannot be obtained by mixture of other colors, (2) the "primary" colors as a group can mix every other color, and (3) all the "primary" colors, mixed together in the correct proportions, produce a dark neutral (black). These criteria were then used to justify the selection of only three "primary" paint colors red (magenta), yellow and blue (cyan). Painters have traditionally been taught to use these "primary" colors as the cornerstones of their palette selection.

In fact, the 18th century **"primary" color criteria justify a much larger paint selection**. For example, it is not possible to mix a saturated orange color with yellow and magenta paints. To fill this gap, most painters add the "unmixable" orange to their palette as an orange or scarlet paint. This in turn allows the painter to mix a more saturated range of deep yellow and red colors, making good on the claim that the "primary" colors can mix *all other colors*. The same demonstration shows that we must also add a green and a violet or deep blue paint as "primary" colors: and the scarlet, green and violet paints mix a much darker black than do magenta, yellow and cyan paints.

However, this discussion is beside the point, because it asserts a "color theory" comparison between *material paints* and *ideal colors*. In practice, theory doesn't matter. A painter is only concerned with practical criteria and color mixing facts to judge his working materials. So the modern painter modifies the traditional "primary" color criteria (http://www.handprint.com/HP/WCL/palette4f.html), and adds three more criteria, when selecting paints for a palette:

1. *Does this paint significantly* ***increase the maximum chroma or color variety*** *in mixtures with other paints on the palette?* In general, chroma has the greatest impact on expanding a palette gamut, and is therefore the most important color attribute of a "primary" paint.

2. *Does this paint significantly* ***extend the darkest values*** *I can mix with this palette?* It is usually preferable to obtain darker color mixtures by using primary paints at their darkest (most concentrated) value, rather than by darkening color mixtures with black.

3. *Does this paint* ***increase the variety of material paint effects*** *I can produce with my palette?* The material attributes of paints transparency, staining, tinting strength, granulation, diffusion wet in wet, and so on are as important as the color attributes.

4. *Does this paint significantly* ***increase my convenience and control when mixing colors****?* If you can reduce painting effort or improve color mixing accuracy by adding a paint to your palette, it is usually a good idea to add the paint.

5. *Does this paint* ***replace an undesirable paint*** *that is not lightfast, does not contribute to the color contrast or color variety, is too expensive, or is too difficult to work with (including toxicity)?* Many paints that are popular today are replacements for undesirable but popular paints of yesterday.

A painter is never interested to add a paint to his palette which entails an increased investment in money, maintenance and space without getting something useful in return. The primary things most painters seek are lightness contrast, hue intensity, color mixture variety, pigment texture, handling attributes (staining, lifting, diffusion), lightfastness, and material quality (pigment load, vehicle purity).

Paints that meet all five criteria are **palette primary paints**. "Primary" does not mean a paint corresponds to any kind of abstract color idea, however defined: it just means the paint is indispensible for color mixing in a given palette, when all the paint mixing attributes are taken into account.

Note that water is used to dilute paint mixtures so that the white of the paper becomes more visible: water adds whiteness to color mixtures. White cannot be mixed from any of the other colors, and at the same time white is essential to create all light valued colors. Therefore **water (white paper) is also a palette primary** in watercolor painting.

Thus, the watercolor painter starts with as many as *eight* palette "primaries" (seven paints including a dark neutral, and water to reveal the white paper).

6 A Six Paint Palette. Using the revised, modern conception of palette "primary" colors as our guide, we can match the six color categories of the hue circle to six colors of paint. This creates a hexachrome or six paint palette (http://www.handprint.com/HP/WCL/palette4e.html). (Spelling note: a *pallet* is a straw bed or shipping platform, a *palate* is the roof of the mouth.)

Although there are many possible paint choices, a suitable and practical palette for learning color through paints is:

yellow (http://www.handprint.com/HP/WCL/palette1.html#yellow) (**Y**): **benzimidazolone yellow** (PY154 (http://www.handprint.com/HP/WCL/watery.html#PY154)) or **cadmium yellow** (light or pale, PY35 (http://www.handprint.com/HP/WCL/watery.html#PY35))

orange (http://www.handprint.com/HP/WCL/palette1.html#redorange) (**O**): **cadmium orange** (PO20 (http://www.handprint.com/HP/WCL/watero.html#PO20)) or **cadmium scarlet** (PR108 (http://www.handprint.com/HP/WCL/waterr.html#PR108))

magenta (http://www.handprint.com/HP/WCL/palette1.html#violetred) (**M**): **quinacridone magenta** (PR122 (http://www.handprint.com/HP/WCL/waterc.html#PR122)) or **quinacridone rose** (PV19 (http://www.handprint.com/HP/WCL/waterc.html#PV19R))

violet (http://www.handprint.com/HP/WCL/palette1.html#violetblue) (**V**): **ultramarine blue** (PB29 (http://www.handprint.com/HP/WCL/waterb.html#PB29)) or **ultramarine violet** (blue shade, PV15 (http://www.handprint.com/HP/WCL/waterv.html#PV15))

cyan (http://www.handprint.com/HP/WCL/palette1.html#greenblue) (**C**): **cobalt teal blue** (PG50 (http://www.handprint.com/HP/WCL/waterg.html#PG50)) or **phthalo blue GS** (PB15:3 (http://www.handprint.com/HP/WCL/waterb.html#PB15))

green (http://www.handprint.com/HP/WCL/palette1.html#green) (**G**): **phthalo green YS** (yellow shade, PG36 (http://www.handprint.com/HP/WCL/waterg.html#PG36)) or **phthalo green GS** (blue shade, PG7 (http://www.handprint.com/HP/WCL/waterg.html#PG7))

Many artists choose a seventh paint as a convenient source for the darkest values:

dark neutral (http://www.handprint.com/HP/WCL/palette1.html#dkshade) (**N**): either carbon black (usually **lamp black**, PBk6 (http://www.handprint.com/HP/WCL/waterw.html#PBk6)), or a convenience mixture of carbon black with a tinting pigment that creates a bias toward green (*payne's gray*), blue (*indigo*), violet (*neutral tint*) or brown (*sepia*).

Other artists prefer instead to mix dark neutrals from two complementary palette primaries. In watercolors, the **darkest neutrals** are mixed with phthalocyanine (http://www.handprint.com/HP/WCL/pigmt1d.html#phthalocyanine) pigments usually a red and blue green paint (phthalo green BS, PG7 (http://www.handprint.com/HP/WCL/mixtable.html#PG7)); or a scarlet and blue paint (phthalo blue, PB15 (http://www.handprint.com/HP/WCL

/mixtable.html#PB15)). In the six paint palette, either the orange and cyan or magenta and green mixtures can be used to make the dark neutral. (For more information on the combinations of watercolor paints that can be used to mix dark neutrals, see the page on watercolor mixing complements (http://www.handprint.com/HP/WCL/mixtable.html).)

Finally, in watercolor paints, the eighth palette "primary" white is provided by water, which dilutes any paint mixture toward the white of the watercolor paper. White watercolor paints are not commonly used because they lack the transparency of other colors, and produce less lightfast mixtures.

As must always happen when material paints take the place of abstract color categories, this six paint palette does not represent an "ideal" color selection. We would like quinacridone magenta to have a bluer hue (http://www.handprint.com/HP/WCL/color5.html#badideal), but the only pigment available at that hue (cobalt violet) is too light valued and weakly tinting. We'd want phthalo blue GS to have a much greener hue (closer to turquoise), but phthalo cyan (PB17 (http://www.handprint.com/HP/WCL/waterb.html#PB17)) is no longer available as a standard watercolor, and phthalo turquoise (PB16 (http://www.handprint.com/HP/WCL/waterb.html#PB16)) is too dark. These issues illustrate that ideal colors do not accurately describe our choices among the colors of physical substances such as paints, inks or dyes.

7 Paint Mixing Lines & Color Mixing Scales. The mixtures between two palette primaries form a unique series of colors, represented by a *paint mixing line* in the palette gamut. By using two primaries at a time, and actually painting out a *color mixture scale* of color samples, the painter learns firsthand the unique sequence of colors that the palette primaries create, and learns the basic skills of working with paints (http://www.handprint.com/HP/WCL/tech14.html).

The goal is to define each mixing line by color mixtures at the midpoint of the line, and halfway between the midpoint and each primary paint in the mixture (diagram, right). This requires 15 mixture scales and 45 unique color mixtures, or 75 color samples if the palette primaries are included at each end of the scale to make a 5 step mixture scale. (Ambitious or inquisitive painters should make 7 step scales, which require 105 separate color samples.) This takes an afternoon to complete, but it is an essential and rewarding first step to learning color through paints.

To prepare these scales, dissolve 1 teaspoon of each palette primary paint in 2 tablespoons of water use the same dilution for all paints. Then for each mixture scale:

On a 9" x 12" watercolor block (CP or cold pressed finish) of your preferred watercolor paper, rule a 1" margin around each side, then in portrait orientation (the 12" side vertical) divide the sheet into 5 rows, and each row into 5 columns.

Use a ½" flat brush to paint a 1" square of each pair of palette primary paints, in the opposite end columns of the first row. (There are 15 primary paint pairs [**Y+O**, **Y+M**, **Y+V**, **Y+C**, **Y+G**, **O+M**, **O+V**, **O+C**, **O+G**, **M+V**, **M+C**, **M+G**, **V+C**, **V+G** and **C+G**], and five pairs will fit on the five rows of a sheet.)

Mix a generous quantity of the two paints on a flat palette until you get a color that appears balanced between the colors of the two primary paints; apply this mixture with the ½" flat brush in the center column of the row.

Mix half the remaining middle mixture with one primary to produce a color that appears midway between them, and paint this color between the middle and primary paint samples.

Do the same for the remaining middle mixture and the opposite primary paint.

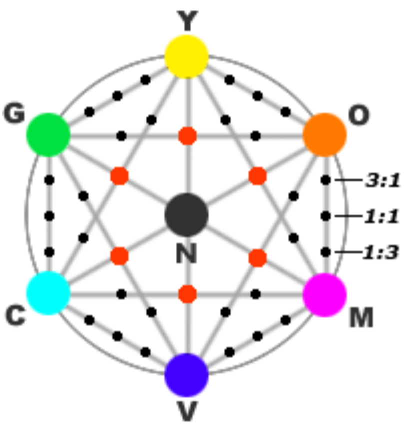
A finished color mixture scale (for yellow and magenta), numbered in the order the samples are painted, looks like this:

color mixture scale between yellow and magenta paints

As you work, make a note of the approximate proportion of paint to paint (e.g., 5 parts yellow to 1 part magenta) necessary to create the middle mixture in each mixture scale ("3" in the diagram, above).

The dilution recipe is generous enough that you will have plenty of paint to work with. It's highly recommended you use the extra paint to dilute each color mixture halfway toward white, and paint these out as diluted duplications of the 15 full strength mixture scales. These add another 15 scales to the exercise, but diluted paints define a different part of the gamut and a very different dimension of the paint color.

Finally, motivated painters should mix a nine step value scale (http://www.handprint.com/HP/WCL/color11.html#scale), using the same "split the middle" method, with the dark neutral (black) paint and water.



15 mixing step scales between the 6 palette primary paints

8 The "Geometry" of the Palette. The primary benefit of the 15 color mixture scales is that they introduce the painter to the gamut space of the six paint palette. However, they also invite comparison of the palette gamut to an *ideal* ("color theory") model of the mixing space as a hexagonal "color wheel" (diagram, right).

The painter can apply this schema to identify and compare the 6 color pairs that are "theoretically" identical in hue and chroma, and the 3 mixtures that should be achromatic (a dark neutral, **N**), disregarding differences in lightness (red dots). He can also examine the 66 color intervals (marked by black dots) that are "theoretically" equally different in hue and chroma if the gamut is in fact perfectly regular and symmetrical. He can draw conclusions from these comparisons about the relative fit between the "terrain" of color mixing facts and "map" of geometrically ideal color wheels, and begin to recognize the uncovered by the six paint palette.

As a help in this study, I used a spectrophotometer to measure my own color mixture scales; then I located them in CIECAM (http://www.handprint.com/HP/WCL/color7.html#CIECAM), a color space used to represent perceived differences in surface colors. These reveal three important facts about the palette gamut as a color mixing space.

The palette used was:

yellow (http://www.handprint.com/HP/WCL/palette1.html#violetblue) (**V**): **benzimida yellow** (PY154 (http://www.handprint.com/HP/WCL/watery.html#PY154))

orange (http://www.handprint.com/HP/WCL/palette1.html#orange) (**O**): **cadmium orange** (PO20 (http://www.handprint.com/HP/WCL

/watero.html#PO20))

magenta (http://www.handprint.com/HP/WCL/palette1.html#greenblue) (**B**): **quinacridone magenta** (PR122 (http://www.handprint.com/HP/WCL /waterc.html#PR122))

violet (http://www.handprint.com/HP/WCL/palette1.html#orange) (**O**): **ultramarine blue** (PB29 (http://www.handprint.com/HP/WCL /waterb.html#PB29))

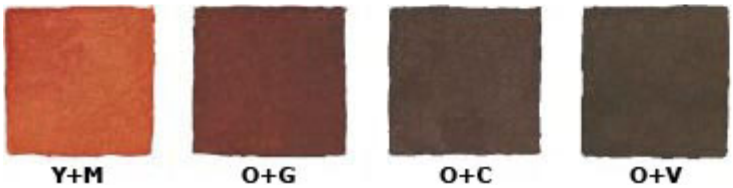
cyan (http://www.handprint.com/HP/WCL/palette1.html#greenblue) (**B**): **cobalt teal blue** (PG50 (http://www.handprint.com/HP/WCL /waterg.html#PG50))

green (http://www.handprint.com/HP/WCL/palette1.html#violetblue) (**V**): **phthalo green** (yellow shade, PG36 (http://www.handprint.com/HP/WCL /waterg.html#PG36))

The first is that the six palette gamut is not balanced around gray: the mixing space defined by the "warm" paints (yellow, orange, magenta and gray) is much larger than the space defined by "cool" paints (violet, cyan, green and gray). Warm surface colors have an inherently greater variety than cool colors.

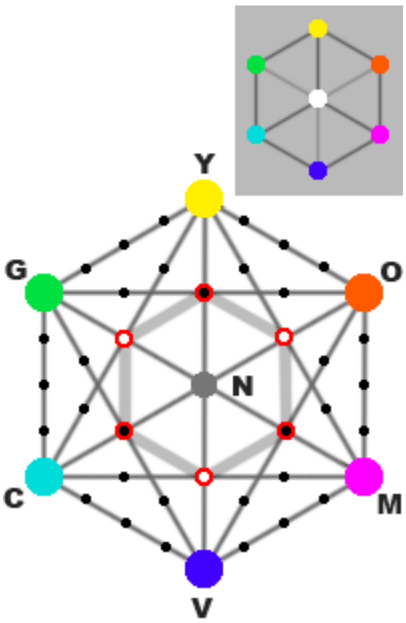
Second, the mixture scales do not generally form straight lines; many are curved. This means the gamut enclosure is not defined by flat planes (as in a cube), but by curving boundaries that can be concave (between orange and yellow) or convex (between yellow and green). It also means that using a "straight line" estimation of the colors produced by two paints will in some cases be significantly inaccurate.

Third, color mixtures that appear similar in a flat (two dimensional) gamut diagram may be quite different visually, because the gamut "map" cannot represent the lightness of the mixing line between two paints, and cannot be used to anticipate the lightness of the color mixtures. The example below shows the four "dull orange" color mixtures enclosed by the square in the diagram (right).



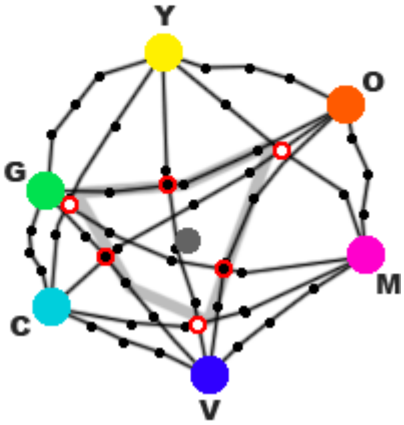
mixtures that appear similar on a gamut "map"

This example shows that we also cannot easily rely on a "scientific" gamut map to indicate in advance the color mixtures produced by paints. In other words, **no diagram adequately replaces experience with paint mixtures** as produced by a specific selection of material paints. Reference to abstract color models is always less effective than learning color through paint mixtures.



color mixture scales as an ideal, hexagonal color wheel

(inset) the ideal scales as a gamut cube



the actual color mixture scales

on the CIECAM ab plane

9 The Palette Gamut. As we leave behind the ideal colors and abstractions of "color theory", we also leave behind the idealized hue circle and its "pure" color categories. In its place, painters rely on a factual description of paint mixing behavior, the gamut (http://www.handprint.com/HP/WCL/color13.html#gamut).

A **palette gamut** is the collection of *all unique colors* that two or more of the palette primary paints can make if they are mixed in any combination, in any proportions including any proportion of water (white paper) in the mixture. Gamuts describe every kind of color media: for example, the collection of all unique colors that can be produced by your computer screen is your computer's *monitor gamut*, and the collection of all unique colors that can be produced by your inkjet printer is your *printer gamut*. You can think of the gamut as a kind of box that contains all the unique palette color mixtures. The larger the box the larger the gamut the more unique color mixtures it can contain.

Each palette primary defines a *corner* of the gamut "box". Mixtures between two neighbor palette primaries, including mixtures with white and black, define a continuous series of color mixtures made with only two paints (); these are the *edges* of the gamut enclosure. When the painter uses his to select paints that provide the maximum lightness contrast, color chroma and color variety, he is choosing paints that define the *largest possible gamut*.

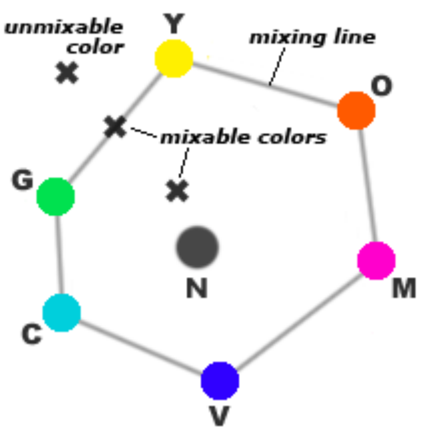
Because it is a factual description of the color mixtures produced by a specific color medium, we can draw a picture of a gamut (diagram, right). We place the palette primary paints in a circular order according to their respective hues, then we place each paint at a distance from a neutral or achromatic point (**N**) according to its chroma or saturation. (More saturated paints are located farther from the neutral gray not at an equal distance from gray, as is commonly done in artist's "color wheels".) Paints with high chroma create a larger number of unique color mixtures with a neutral gray; light paints create a larger number of mixtures with black, and dark paints create a larger number of mixtures with white.

When we complete a gamut diagram using these simple rules, we find that **a real gamut does not form a symmetrical circle** but an irregular hexagon. This hexagon encloses *all mixable colors*, whether mixed by two primaries, three or more. Any color lying outside the gamut is an *unmixable color* for the palette (though it may be mixable in some other color system).

If we view the gamut from the side, so that we can also display the mixing lines between each primary paint and white and black, we can see the lightness differences (http://www.handprint.com/HP/WCL/vwheel.html) among the palette paints (diagram, right). We discover that the irregular hexagon is actually a cross section of a double pyramid enclosure, with two peaks at white and black. Some paints (yellow, orange) are closer to white, and others (cyan, violet) are closer to black. The interior diagonal from white to black defines the artist's value scale (http://www.handprint.com/HP/WCL/color11.html#scale) or grayscale. (To minimize confusion, it is helpful to visualize this gamut as a cube, with the six palette primaries, white and black at each corner [inset, right].)

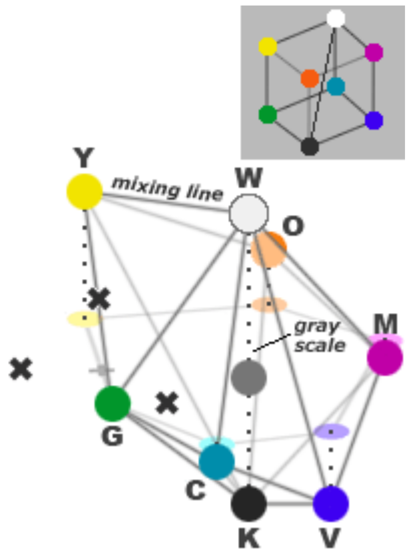
Because most surface colors, including paint colors, are rather dull, **no paint palette can mix all visible colors**. This is obviously true for the colors of gems, stained glass, prism spectrums, colored lights and fluorescing or "dayglo" pigments. More important, this is also true of intensely tinted surface colors, including porcelains, tiles, enamels, many flowers or dyed fabrics. These **unmixable colors lie outside the gamut**. How we simulate them within a painting (or a photographic print) is the complex problem of fitting a larger gamut within a smaller gamut, known as gamut mapping (http://www.handprint.com /HP/WCL/color11.html#paintzone).

A watercolor palette gamut is also affected by the that the paints are applied to in particular the lightness or reflectivity of the paper, the whiteness or color tint of the paper, the surface finish (texture and sizing) of the paper, and the tendency of the paper to hold paint on its surface rather than soak paint into its inner fibers. The largest gamut is produced by very reflective, white papers with a smooth, well sized finish that holds all the paint on the surface. To see this, apply and compare the same paint mixtures on high quality watercolor paper (nonabsorbent, reflective, untinted) and on newsprint sketch paper or gray construction paper (absorbent, less reflective, tinted).



gamut diagram of the six paint palette

(excluding white and black)



side view of the six paint gamut including white (W) and black (K)

(inset) the gamut visualized as a color cube

10 Locating a Gamut Color. If we use a color measuring instrument called a *spectrophotometer,* we can be more precise in making the gamut map, so that it accurately shows the hue, lightness and chroma of all color mixtures.

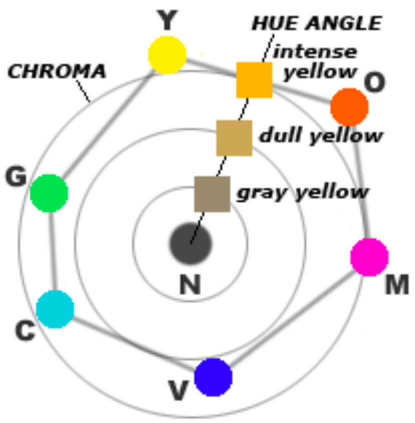
Hue is represented in the gamut by the *clock face location* or **hue angle** of the color around the gray or neutral center of the gamut (**N** in the gamut diagram): yellow (**Y**) is approximately at 12 o'clock, orange (**O**) at 2, magenta (**M**) at 4, blue violet (**V**) at 6, cyan (**C**) at 8 and green (**G**) at 10. (Hues are often reversed, with red on the left, in art school color wheels in the USA.)

The hue angle created by a straight line from the neutral center through the gamut boundary shows the proportions of the two closest palette primaries that will mix the most saturated or intense version of that hue. For example, a hue line that points to 11 o'clock on the gamut is halfway between the yellow (**Y**) and green (**G**) palette primaries, and therefore is a yellow green that can be matched by a mixture of equal parts green and yellow paint (assuming the paint solutions are of equal tinting strength).

Chroma is represented in the gamut by the distance of a palette primary or paint mixture from the center toward the edge of the gamut. Paints or paint mixtures at the center of the gamut are very dull, gray, or neutral (**N**). Paints or mixtures close to the edge of the gamut are the most intense (saturated) available in mixtures of the palette primaries.

In all paint palettes, the palette primaries do not have equal chroma and therefore are not equally far from the neutral center. This affects their color mixtures.

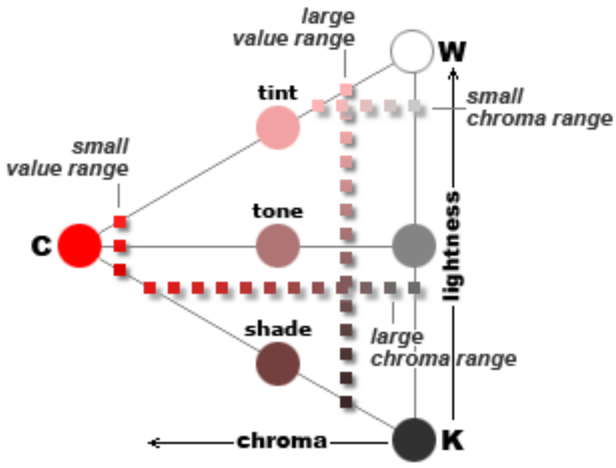
Lightness is not shown in the gamut diagram because it is the most obvious color attribute; and by omitting it, hue and chroma can be represented clearly. However, it is understood that the gamut tapers to a point at white and black: as mixtures become lighter or darker, the width of the gamut contracts and the number of unique colors grows smaller.



locating colors in a gamut diagram

11 Shades, Tones, Tints. Although it is often omitted from a gamut diagram, lightness is of key importance to painters. And painters from the Renaissance to the present have identified three categories of paint mixture that focus on the

relative change of the pure paint on lightness and/or chroma (diagram, below).



tints, tones and shades of a paint

tints are produced by mixture of a paint with white (or dilution with water); these are always *lighter and less intense* than the pure paint.

shades are produced by mixture of a paint with a black, dark neutral or dark neutral mixture; these are always *darker and less intense* than the pure paint.

tones are produced by mixture of a paint with a neutral or gray color, or with a of similar value; these are always *less intense at a similar lightness*.

The diagram also illustrates a useful rule to visualize the gamut enclosure: **as lightness contrast increases, chroma contrast decreases** (and vice versa). Working with paints at high chroma defines a small variation in lightness of the same hue, and working with paints at high (or low) lightness defines a small range in chroma within the same hue. This rule applies even when the paint color is very light (yellow) or dark (violet).

The difference between a tint and tone, or a tone and shade, is not hard and fast. It depends on whether the loss of chroma is more pronounced than the change in lightness (tones), or whether the color has become noticeably lighter (tints) or darker (shades).

12 The Most Saturated Paint Mixture. When we say a palette primary paint defines a corner of the palette gamut, we mean that the paint is used at its *maximum chroma* or saturation. But raw paint straight from the tube is very dark and gummy, while diluted paint is very weak and whitened. So where is the point of maximum chroma, and how do painters find it?

A paint or paint mixture reaches its maximum chroma or color purity at a "not black, not light" (http://www.handprint.com/HP/WCL/tech16.html#notblack) dilution. For most paints, this is at a ratio of paint to water between 1:4 to 1:6 (http://www.handprint.com/HP/WCL/tech16.html#cshortcut). From the point of peak chroma, color saturation is always reduced by diluting further with water or white paint. The image (below) shows the full chroma range for a common green pigment, phthalocyanine green BS (PG7 (http://www.handprint.com/HP/WCL/waterg.html#PG7)).

dilution series for phthalocyanine green BS

the dot indicates the dilution with the highest chroma

The best ratio of paint to water is different for different pigments (http://www.handprint.com/HP/WCL/tech16.html#cshortcut) and the same pigment in different paint brands. But each paint and paint mixture goes through characteristic changes (http://www.handprint.com/HP/WCL/tech16.html#mixswat) as it is diluted from high concentration into tints or tones: more diluted paints tend to show more pigment texture, and gain lightness at the same time that they lose chroma or saturation. The painter must explore paints at all concentrations to learn how to produce this color range and learn its use in painting.

The hue of a paint or mixture may change as it is lightened with water or white paint. Typically, deep yellow, orange, green and blue paints appear to become more yellow in tints; deep reds and violets seem to shift toward blue, and very dark or dark neutral paints, which appear to have no hue, will acquire a blue or green hue in tints. Green gold (PY129 (http://www.handprint.com/HP/WCL/waterg.html#PY129)) paints appear green in masstone but yellow in tints (image, right). The hue of a yellow paint appears to shift toward green if it is darkened with a gray, black, blue or blue violet paint; it becomes brown if darkened with purple or magenta.

The idea that watercolors create a unique "luminosity", by light that is reflected from the paper and passes through the paint "like light through a stained glass window" is only a picturesque myth (http://www.handprint.com/HP/WCL/tech16.html#luminositymyth) handed down from English Victorian era painters.

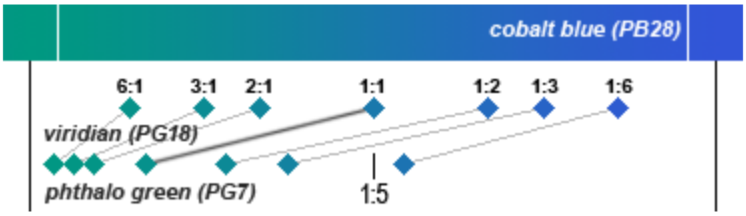
color change in green gold paint

from masstone (left) to tint (right)

13 Tinting Strength. In preparing the mixing step scales, including the tint scales, the painter recognizes that some palette primaries assert themselves in a paint mixture more than others; more of the weaker paint is required to produce a color that appears midway between the two paints. This strength or dominance in

mixtures is the tinting strength (http://www.handprint.com/HP/WCL/pigmt3.html#tinting) of the paint.

The reason for diluting equally all the six palette paints is to make their tinting strength clear in color mixtures. The paint tinting strength depends on both the pigment tinting strength (http://www.handprint.com/HP/WCL/tech16.html#dilval) and the *pigment load* when the proportions of paint to water (or chromatic paint to white paint) are equal across all paints compared.



effect of tinting strength on paint mixtures

phthalo green with 5 times the tinting strength of viridian and cobalt blue

In the example (diagram, above), viridian and cobalt blue, both granulating mineral pigments, have roughly the same tinting strength: mixing the two paints in equal proportions (1:1) at equal dilution produces a blue green hue midway between them.

Phthalocyanine green (PG7 (http://www.handprint.com/HP/WCL/waterg.htl#PG7)) has a color almost identical to viridian but a much higher tinting strength. If it has 5 times the tinting strength of cobalt blue, then the quantity of cobalt blue in the mixture must be 5 times greater (1:5) in order to produce the hue midway between them; the 1:1 mixture will appear very similar to pure phthalocyanine green.

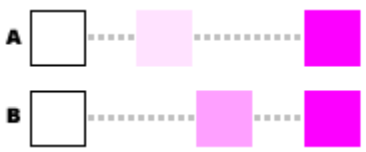
Tinting strength can be measured in two ways (http://www.handprint.com

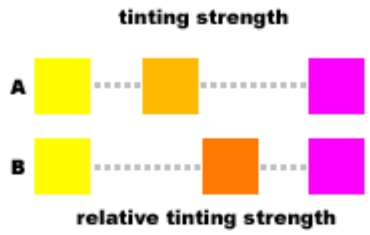
/HP/WCL/pigmt3.html#tinttest) (diagram, right): (1) the relative hue of a mixture of two paints in equal physical proportions; or (2) the darkness or intensity of the tint produced by a 1:10 mixture of the paint with titanium white paint, or in a 1:100 mixture of the paint in water. In the first example (right, top), the tinting strength of the magenta paint **B** is higher than paint **A**, because it produces a darker, more saturated color in an equal proportional mixture with white paint. In the second example (right, bottom), the relative tinting strength of the magenta paint is greater (or the relative tinting strength of the yellow paint is less) in **B** compared to **A**, because the mixed hue is closer to magenta than to yellow.

Method (1) is the technical standard, because the "tint" mixtures can be easily and accurately compared by the relative lightness of the colors alone; but method (2) falls in the common experience of painters mixing paints especially when, as in the mixture scales, the aim is to create a hue midway between the two paints. If the midway hue is achieved, then the proportion of the two paints in the mixture is equal to the proportional difference in their tinting strengths (diagram, above).

In most brands of watercolor paint, benzimidazolone yellow (PY154) has very low tinting strength, ultramarine blue (PB29) has low tinting strength, quinacridone magenta (PR122) and phthalocyanine green (PG36) have moderate tinting strength, and pyrrole orange (PO73) and phthalocyanine blue (PB15:3) have very high tinting strength.

The painter learns the relative tinting strengths of all paints on his palette, as this minimizes the amount of effort and added paint necessary to get the desired color in paint mixing. She also learns that some brands of paint have higher tinting strength than others, which usually means the pigment load is higher.





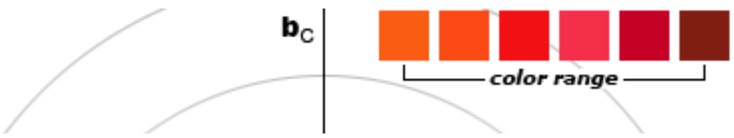
two measures of paint tinting strength

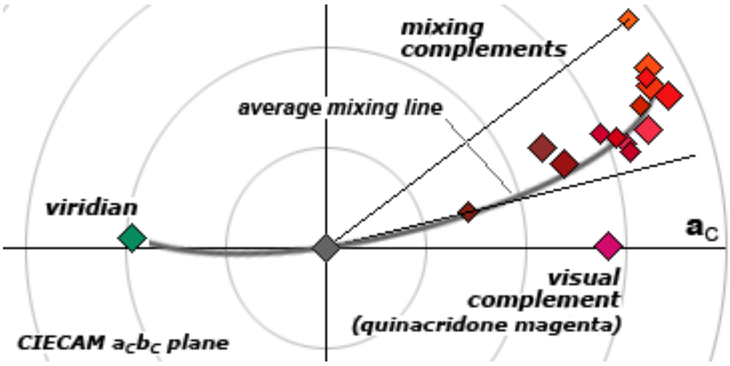
(top) 10:1 mixtures of titanium white paint and colored paint; (bottom) 1:1 mixtures of two colored paints

14 Visual & Mixing Complements. A major interest of 19th century "color theory" had to do with mixing complementary colors (http://www.handprint.com/HP/WCL/color13.html#compprobs), or two paints that, in the right proportions, mix to a **pure neutral** or gray color.

Mixing complements are different from **visual complementary colors**, which are colored *lights* that produce a gray mixture. In many cases, especially between "warm" and "cool" hues, the mixing and visual complements are not the same.

As we might expect from the irregularities in the palette gamut just discussed, it is not possible to create a color wheel that summarizes mixing complement relationships. There are two reasons: any single paint can be the mixing complement of many different paint "colors" on the opposite side of the hue circle, and two paints of matching color can have completely different mixing complements. (To avoid these problems, I present the watercolor mixing complements (http://www.handprint.com/HP/WCL/mixtable.html) as a list rather than a "color wheel" diagram.) In contrast, visual complement relations are explicit and unambiguous: a single hue is always the visual complement of any color, in the same way that a single gray is the lightness match to any color.





visual & mixing complements to viridian

displayed on the CIECAM $a_C b_C$ plane

As one example, the *visual complement* of the beautifully granulating, blue green pigment viridian (PG18 (http://www.handprint.com/HP/WCL/waterg.html#PG18)) is a hue that is closely matched by the pigment quinacridone magenta (PR122 (http://www.handprint.com/HP/WCL/waterc.html#PR122)). No other pigment fits this role as well.

But the mixing complements (http://www.handprint.com/HP/WCL/mixtable.html#PG18) of viridian include pigments that range in color from red brown (benzimida maroon, PR171 (http://www.handprint.com/HP/WCL/waterc.html#PR171)), to maroon (perylene maroon, PR179 (http://www.handprint.com/HP/WCL/waterr.html#PR179)), to carmine (anthraquinone red, PR177 (http://www.handprint.com/HP/WCL/waterc.html#PR177)), to deep red (naphthol red deep, PR170 (http://www.handprint.com/HP/WCL/waterr.html#PR170)), to light middle red (quinacridone red, PR209 (http://www.handprint.com/HP/WCL/waterr.html#PR209)), to dark middle red (pyrrole red, PR254 (http://www.handprint.com/HP/WCL/waterr.html#PR254)), to scarlet (naphthol scarlet, PR188 (http://www.handprint.com/HP/WCL/waterr.html#PR188)), to red orange (pyrrole orange, PO73 (http://www.handprint.com/HP/WCL/watero.html#PO73)). These are clearly not the same color, or even the same hue. At the same time, several of these paints (such as perylene maroon) are mixing complements of bluer (turquoise) paints as well the mixing complement confusion appears on both sides of the hue circle.

Thus, visual complements are reliable and meaningful guides to color design. Mixing complementary *pigments* are helpful to know in order to mix neutral tones effectively, but they cannot be summarized as *hue contrasts* around the hue circle because **paint color is not a reliable guide to the color of paint mixtures**. (See substance uncertainty (http://www.handprint.com/HP/WCL/color5.html#subprobs) for a full explanation of this problem.)

It is not possible to create an idealized gamut map or "color wheel" that accurately represents *paint mixtures* as *color relationships*. Two paints with the same color will make different color mixtures with other paints, and (as the mixing complements demonstrate), different colored paints can mix the same color (gray) with a single paint. This is why it is important to keep clear the difference between *paints* and *colors*.

15 The Basic Mixing Method. The previous section summarizes what most painters discover gradually and by experience:

a palette gamut geometry is never simple or ideal (it is not hexagonal or cubical)

the actual path of paint mixing lines cannot be known from a theory (they are sometimes straight, sometimes curved)

the color space is shaped by quirky exceptions or imbalances (there is greater variety in warm than in cool color mixtures), and

the "color" of paints is a very poor guide to their effects in mixtures with other paints (the variety of colors in the same mixing complement relationship).

In response to these insights, the painter adopts a more pragmatic method to creating color mixtures: he learns that mixtures must be *improvised*.

This basic mixing method (http://www.handprint.com/HP/WCL/mix.html) relies on an abstract gamut diagram only for a single judgment: to **locate the desired color mixture within a triangle defined by three palette primaries**. If this can be done, then it is certain that the desired color can be produced by some combination of the three paints in the right proportions or dilution ratios.

Experience also uncovers some basic working principles that minimize inaccuracy and waste in paint mixing:

1. Use no more than three paints whenever possible.

2. Use the "gamut map" to identify *all possible combinations* of three paints that enclose the desired color in a triangle, then choose from among these the three paints (triangle points) with the specific qualities (typically tinting strength, staining, transparency, pigment texture and behavior wet in wet) that are most desirable.

In the gamut diagrams, right, the target color is enclosed by at least 6 different three paint combinations: **Y+O+V**, **Y+M+V** [shown], **Y+M+C**, **Y+M+G**, **O+M+G** and **O+V+G**; the diagrams also suggest that the mixture scales **O+C** or **O+G** may be able to match the color.

Note that the **Y+O+...** or **Y+M+...** mixtures will tend to be light valued, while the **O+...** mixtures will tend to be dark valued, as . Pigment combinations also allow control over the mixture lightness.

3. Always start the mixture with the two paints that define a mixing line closest to the desired color mixture on a color wheel or gamut map ("short" mixing method), if the goal is precise control of the mixture hue and chroma. Start with the two paints that create the far "base" of the mixing triangle ("long" mixing method) if the goal is to create near neutral (dull) mixtures across a range of hues (for example, to model color transitions from shadowed to illuminated surfaces). (Compare the two diagrams, right.)

4. Always use the weakest tinting of the two paints to mix the approximate quantity of paint desired, and make this mixture more concentrated (darker) than wanted, as it will be diluted by the other paints and can be easily lightened with added water. If possible, use the strongest tinting paint only to make final adjustments to the color.

5. If precise control is desired, or you are unfamiliar with the drying shifts typical of the paints, paint out the mixture on watercolor paper, and let this test mixture dry for at least 5 minutes to examine the mixture color.

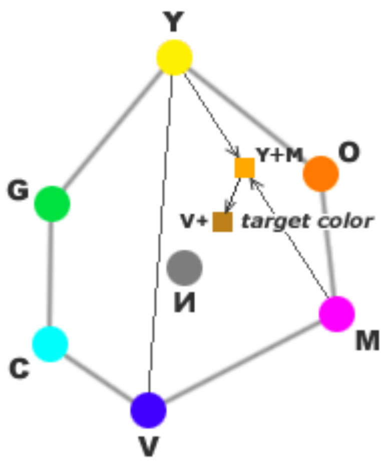
6. If you overshoot the mixture and must add more of the weakest tinting paint, it is less wasteful to pour off some of the mixture first, to reduce the amount of new paint it is necessary to add.

7. As the last mixing step, add water or a fourth paint (such as a dark neutral), as necessary, to make final adjustments to the lightness and/or chroma of the mixture.

In many situations, a two paint mixture (a color on the mixing line between two palette primaries) comes very close to the desired color. Many painters learn the color mixture scales of their palette so intimately that they can use them as a kind of keyboard, hitting each "note" without using three paints in a mixture. This has the benefit of giving the painting a regularity and pattern in the color variations that produces a recognizable "all over" tonality in the color design, while detracting little from color realism.

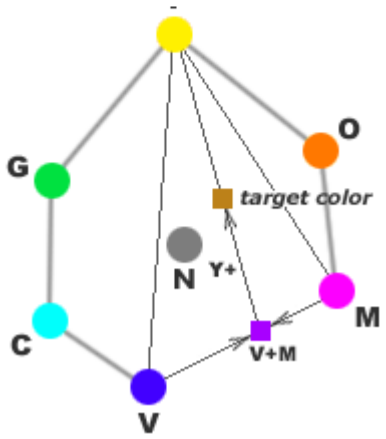
However, realist painters will attest that at least **four palette primaries are necessary for an exact color match**, and photorealist painters may even use five or six paints to get a color "exactly right". Why? Because mixtures among three of the eight palette primaries only define flat "slices" through the gamut space. Many color mixtures are embedded in the gamut between these slices. The fourth primary creates a pyramid which will enclose all additional color mixtures. Very often, this fourth primary is water (dilution to white) or the dark neutral.

Using the basic mixing method, it does not matter that some mixing lines are curved or that the gamut shape is irregular. The gamut diagram or color wheel is only used to identify a (usually very large) mixing triangle that contains the color you intend to mix; everything else proceeds by watching the mixture as it develops.



the basic mixing method (short)

the "short" method is useful for precise control of the mixture hue and chroma



the basic mixing method (long)

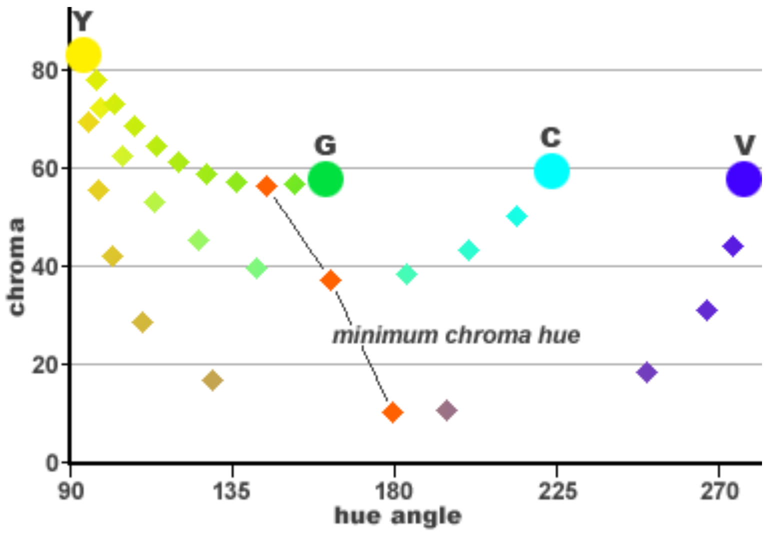
the "long" method is useful to mix similar near neutrals across a wide span of hues

16 Saturation Costs. The six paint palette has been chosen to include paints with the highest chroma in their hue, to provide the most saturated color mixtures between neighbor palette primary paints and (another way to say the same thing) the largest gamut enclosure possible.

Some painters enjoy working with the brightest colors possible, but others prefer more muted color mixtures and a smaller (sometimes darker or lighter) gamut. Either way, the painter needs to understand saturation costs (http://www.handprint.com/HP/WCL/color14.html#satcost), or the **loss of saturation caused by paint mixture**.

The first rule of saturation costs is: **the farther apart two paints are in the gamut, the duller and/or darker their mixture will be** (diagram, right). An *intense green* results from the mixture of neighbor palette primaries (**Y+G**), a slightly darker *dull green* results from the mixture of distant palette primaries (**Y+C**), and a dark, *gray green* results from the mixture of opposite (near mixing complement) palette primaries (**Y+V**).

Gamut distance affects saturation costs because the mixing line between more distant paints must pass closer to the achromatic (gray) point of the gamut (diagram, below). As mixing lines are , rather than straight, the distance between the two paints in the gamut is a more consistent guide, and easier to remember. (See also the diagram of .)



saturation costs and paint color distance

The second rule of saturation costs is: **chroma typically reaches its minimum near the center of the mixing line**. The exception: the minimum point also shifts toward the duller and/or darker of the two paints when the paints are gamut neighbors (and ignoring tinting strength).

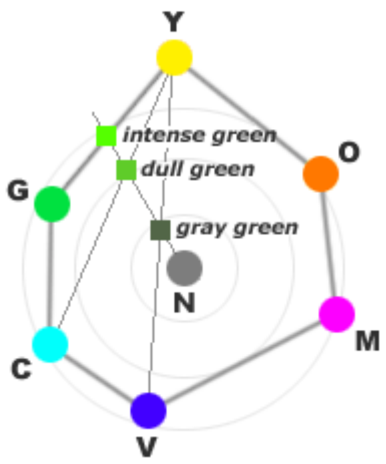
In the three mixing lines shown in the diagram (above), the **G**, **C** and **V** paints all have a similar lightness, and a similar chroma that is ¼ less than the **Y** chroma. Because **C** and **V** are distant from **Y** in the gamut, the minimum chroma mixture is near the center of the mixing lines between them (**Y**+**C** and **Y**+**V**). But because **Y** and **G** are neighbors in the gamut, the minimum point shifts toward **G** on the **Y**+**G** mixing line.

The third rule of saturation costs is: **any mixture of three or more palette**

primaries is always duller and/or darker than the mixture of two neighbor primaries. For example, a mixture of three paints such as **Y+G+C** or **Y+G+O** or **Y+G+M** or **Y+G+V** will always be duller and/or darker than the mixture of the two neighbor paints **Y+G**.

The fourth and last rule of saturation costs is: **saturation costs are greater in mixtures between warm and cool paints** than in mixtures of warm paints among themselves or cool paints among themselves. Warm colors are roughly within the gamut area bounded by magenta, orange, yellow and gray; cool colors are roughly in the area bounded by violet, cyan, green and gray.

Purple and yellow green paints, in the remaining areas of the gamut, tend to mix equally well with both warm and cool paints. Thus, dioxazine violet (PV23 (http://www.handprint.com/HP/WCL/waterv.html#PV23)) mixed with green paint makes a dull blue, and mixed with an orange paint makes a dull red (brown) or dull magenta (maroon). Green gold (PY129 (http://www.handprint.com /HP/WCL/waterg.html#PY129)) mixed with a magenta paint makes an ochre, and mixed with a blue paint makes a dull green.



saturation costs increase with distance between paints

17 Paint Mixing Lore. There are several specific rules for changes in paint lightness, lightfastness and tinting strength that apply to all paints and all paint

mixtures:

The lightness of an equal mixture of two paints is always closer to the darker paint in the mixture (in all art materials, "dark" has a greater tinting strength than "light").

The tinting strength of a paint cannot be increased; it can only be reduced by mixing it with water.

The tinting strength of a mixture is the average tinting strength of the paints in the mixture.

Lightening a paint by mixture with white paint (http://www.handprint.com/HP/WCL/waterw.html#PW4) or water typically reduces the lightfastness of the paint mixture, sometimes drastically; mixture with other paints, including black paint provided all the paints are lightfast has a negligible effect on lightfastness.

The lightfastness of a mixture is usually no greater than the lightfastness of the least permanent paint in the mixture.

Many red (http://www.handprint.com/HP/WCL/waterr.html) and bluish red (http://www.handprint.com/HP/WCL/waterc.html) pigments, and some commercial convenience mixtures (especially convenience green (http://www.handprint.com/HP/WCL/waterg.html#greens) and convenience purple (http://www.handprint.com/HP/WCL/waterv.html#purples) mixtures of a warm and a cool pigment) are the most common source of lightfastness problems.

Much more than other painting media, watercolors generally lighten and whiten (lose chroma) as they dry, because watercolor paints do not form a paint layer, and the dry, uncoated pigment particles tend to reflect more white light. These drying shifts (http://www.handprint.com/HP/WCL/cdsp.html) must be learned by experience; as rules of thumb, cool (green, blue or purple) paints, black (carbon pigment) paints, dark paints and concentrated paints shift more in chroma and lightness than warm (red, orange or yellow) paints, cadmium or cobalt paints, lighter valued paints, and heavily diluted paints.

18 New Paints, New Gamut. Very few painters will be content with the six paint palette used in the previous topics. They will exchange some paints for others, or add more paints to their palette. As they proceed along this path, they begin to see color mixing facts that have less to do with specific paint choices, and more to do with a dimly recognized but fundamental **color mixing landscape**. This is the final stage in learning color through paints.

The palette gamut, and mixing lines within it, will change if any substitution is made in the palette paints. Changing just one paint in the six paint palette changes 5 out of 15 color mixture scales; changing two palette primaries changes 9 out of 15. This is why painters prefer to work with the same palette across many different paintings, and why the landscape becomes an issue so quickly for painters who enjoy trying new paints.

As an example, consider the gamut changes that result from three substitutions in the six paint palette:

orange (http://www.handprint.com/HP/WCL/palette1.html#orange) (**O**): **pyrrole orange** (PO73 (http://www.handprint.com/HP/WCL/watero.html#PO73))

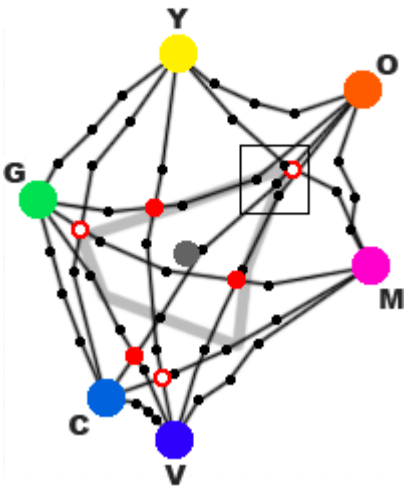
cyan (http://www.handprint.com/HP/WCL/palette1.html#greenblue) (**B**): **phthalo blue** (green shade, PB15:3 (http://www.handprint.com/HP/WCL/waterb.html#PB15:3)) violet (http://www.handprint.com/HP/WCL/palette1.html#violetblue) (**V**): **ultramarine violet BS** (blue shade, PV15 (http://www.handprint.com/HP/WCL/waterb.html#PV15))

If we examine this palette as a CIECAM gamut map (diagram, right), the new paint selection appears to correspond more closely to an ideal . So it might seem to be the better palette. But if we examine the color mixture scales produced by this palette, we find the *color changes* are more complex.

three color mixture scale comparisons

(top) **O+C**; (middle) **M+C**; (bottom) **G+C**

The change of orange and cyan paints creates a lighter valued gray but a more interesting, lighter valued contrast of browns and greens (top rows). The cobalt teal produces a pleasingly granulating but also lighter valued range of blues and purples with magenta (middle rows). The mixtures with phthalo green (bottom rows) are also lighter valued and more granulating, but are also more unnatural as foliage greens.



gamut map of color mixture scales using a different paint selection

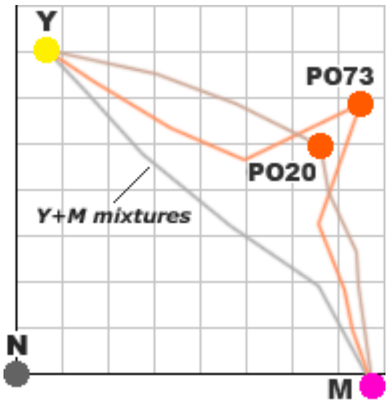
shown on the CIECAM ab plane; white dots indicate the new paints

Finally there is a subtle but important difference in the effect of the two orange paints. The cadmium orange (PO20) has a somewhat *lower chroma* than the pyrrole orange (PO73). From that fact we might assume that all the mixtures of the cadmium orange with the yellow or magenta paints will have a lower chroma than the same mixtures made with pyrrole orange.

And we would be wrong. The diagram (right) superimposes the mixture scales from the two orange paints on the CIECAM gamut map, and shows that the cadmium pigment actually produces the more intense mixtures, especially in yellow hues.

This is another example of the color mixing principle that **paint color is not a reliable guide to the color of paint mixtures**: even the *chroma* of a paint is not a reliable guide to the chroma of its mixtures. These tradeoffs and mixing effects must be learned through experience by actually mixing paints and using the color mixtures in paintings. They can never be understood by studying "color theory" diagrams.

Experience with the same palette primaries improves color mixing accuracy and skill in producing subtle color variations. Many painters work with the same, limited selection of paints, and if they adopt new paints, they do so either for color variety in a specific situation, or use the paints as spot (unmixed) colors.



differences in mixing lines from two saturated orange paints

on the CIECAM $\mathbf{a}_C\mathbf{b}_C$ plane

19 Expanding the Gamut or Palette. The common result of experimenting with different paints and paint combinations is that painters expand their palette beyond the original six paints. Usually a dozen paints (http://www.handprint.com/HP/WCL/palette5.html) seems generous without being excessive. The additional paints fall into two categories: (1) tertiary primaries (http://www.handprint.com/HP/WCL/color13.html#tertiary) around the hue circle, or (2) **interior paints** whose mixing lines fall entirely within the gamut, and are not "primary" because they do not create a gamut corner and none of their mixing lines defines a gamut boundary.

Tertiary Primary Paints

yellow orange (**YO**), often given the marketing names *indian yellow, gamboge* or *deep yellow* in commercial watercolors, is a common and useful choice: good single pigment paints include nickel dioxine yellow (PY153 (http://www.handprint.com/HP/WCL/watery.html#PY153)) or isoindolinone yellow (PY110 (http://www.handprint.com/HP/WCL/watery.html#PY110)). It is difficult to mix a really saturated color in this hue from red orange and yellow, making this a true primary paint. Deep yellow is very useful in muted foliage green mixtures with green, cyan and blue; it mixes lovely light valued tans and pinks with violet and magenta. (Recall that the warm side of the gamut has higher chroma and encloses more unique color mixtures than the cool, so more paints are useful on warm side of the gamut.)

red (**R**) is also a common choice, primarily for the convenience of having an alternate anchor point for floral, flesh (portrait) and landscape mixtures, and to mix very dark near neutrals with a blue green paint. Most artists prefer a rather dull red, an interior paint such as cadmium red deep (PR108 (http://www.handprint.com/HP/WCL/waterr.html#PR108)) or perylene maroon (PR179 (http://www.handprint.com/HP/WCL/waterr.html#PR179)); others go for a very saturated palette primary red, such as quinacridone red (PR209 (http://www.handprint.com/HP/WCL/waterr.html#PR209)) or pyrrole red (PR254 (http://www.handprint.com/HP/WCL/waterr.html#PR254)).

purple (**P**) is a rare choice; the hue is easy to mix from quinacridone magenta and ultramarine (blue or violet), the color is rarely called for in saturated form, and in dull form it most commonly used as a shadow color (see the comments under *shadow* below). The most intense purple paint is dioxazine violet (PV23 (http://www.handprint.com/HP/WCL/waterv.html#PV23)), which greatly extends the purple side of the gamut and is a true palette primary.

blue (**B**) is a very common choice; both to provide greater variety in pigment texture, as a mixing complement to orange, and as a convenience to avoid mixing blue, a common landscape color (see comments under *sky* below). Choices here are limited by the small number of distinctive, saturated blue pigments; cobalt blue (PB28 (http://www.handprint.com/HP/WCL/waterb.html#PB28)) and cerulean blue (PB35 (http://www.handprint.com/HP/WCL/waterb.html#PB35)) add little *color* to a gamut with ultramarine blue and phthalo blue: rather they are prized for their beautiful pigment texture, ease of lifting, docile behavior wet in wet, and reliable lightfastness.

blue green (**BG**) is a common choice, specifically by choosing phthalocyanine green BS (PG7 (http://www.handprint.com/HP/WCL/waterg.html#PG7)), which is a palette primary, as a replacement for the phthalo green YS (PG36 (http://www.handprint.com/HP/WCL/waterg.html#PG36)) in the six paint palette. The saturated color is uncommon in nature, while the dull color is characteristic of tropical or evergreen foliage. However, by choosing a blue green, painters get *duller and darker* green mixtures with any yellow, deep yellow or orange paints on the palette, and these dull greens make more natural landscape and botanical colors. In addition, phthalo blue green is an effective pigment to dull and darken any warm hued mixture, and it makes the darkest neutral mixtures with red synthetic organic pigments. Cobalt teal blue (PG50 (http://www.handprint.com/HP/WCL/waterg.html#PG50)) is a relatively new pigment in this hue, light valued but also very saturated, that is gaining popularity, especially as a landscape palette primary.

yellow green (**YG**) is not a choice: there are no pigments in this hue range that qualify as palette primaries, and all saturated yellow green paints are convenience mixtures.

Interior Paints

Why would a painter increase the palette with a paint that adds nothing to the gamut? The answer: *convenience* and *control*. These interior paints occupy color areas that a painter would otherwise need to mix frequently; or the paints anchor a specific color location that creates a network of very useful mixture scales with all other paints in the palette.

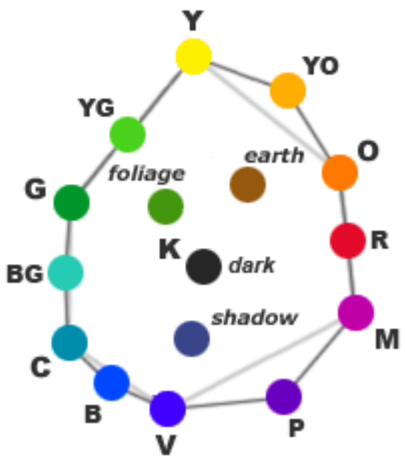
earth colors were originally colored clays mined in Italy and the Near East; sold under the marketing names (http://www.handprint.com/HP/WCL/watere.html) *yellow ochre, raw sienna, burnt sienna, raw umber, burnt umber* and *venetian red* (and many colorful variations (http://www.handprint.com/HP/WCL/color13.html#names)), these ochre, gold, tan, brown and rust colored paints are equally useful in landscape, botanical and portrait/figure painting. Nearly all are synthetic iron oxide pigments or synthetic organic pigments that match their hues.

foliage or dull green colors are common interior paint additions to a palette because greens are frequently required in landscape or botanical painting and would otherwise have to be mixed from a blue and yellow or green and yellow paint. The majority of these paints are convenience mixtures made with phthalo green (either blue shade PG7 (http://www.handprint.com/HP/WCL/waterg.html#PG7) or yellow shade PG36 (http://www.handprint.com/HP/WCL/waterg.html#PG36)), but some painters find a lot to like in the single pigment greens chromium oxide green (PG18 (http://www.handprint.com/HP/WCL/waterg.html#PG18)), viridian (PG18 (http://www.handprint.com/HP/WCL/waterg.html#PG18)) or cobalt turquoise (PB36 (http://www.handprint.com/HP/WCL/waterb.html#PB36)). Green gold (PY129 (http://www.handprint.com/HP/WCL/waterg.html#PY129)), which is actually a muted greenish yellow, can switch hit to mix beautiful warm colors with orange, red or magenta paints, as well as lovely foliage colors with any green or blue paint.

sky colors are useful for landscape painting, and both cerulean blue (PB35 (http://www.handprint.com/HP/WCL/waterb.html#PB35)) and iron [prussian] blue (PB27 (http://www.handprint.com/HP/WCL/waterb.html#PB27)) have been perennial favorites: they mix exellent foliage greens and provide a useful dulling effect in flesh tone mixtures.

shadow colors are commonly purple or blue violet, and as shadow colors must be applied as tints (to avoid overwhelming other colors in the painting or producing a strident shadow contrast), mixing them is not an inconvenience; however indanthrone blue (PB60 (http://www.handprint.com/HP/WCL/waterb.html#PB60)) is a near palette primary on the dark side of the gamut and creates an excellent shadow tint.

dark colors are sometimes dismissed with the quaint 19th century dictum that watercolorists should avoid black paints. Nonsense. The obtrusive, dull drying shift (http://www.handprint.com/HP/WCL/cds.html) that characterizes all carbon black convenience mixtures when used full strength disappears when the paints are used to somewhat darken color mixtures or model shadowed surfaces; and dullness is not noticeable when the paints are used full strength as accent darks or in texture effects. Commercial watercolors offer dark neutrals as pure lamp black (PBk6 (http://www.handprint.com/HP/WCL/waterw.html#PBk6)), or as black tinted with brown (*sepia*), violet (*neutral tint*), blue (*indigo*) or green (*payne's gray*).



expanding the palette

many painters expand their palettes for mixing convenience and greater color variety

20 Mixing Space Quirks. Experience with different combinations of palette "primaries" reveals some fundamental and important quirks in the mixing capabilities of any palette (diagram, right). These arise from peculiarities in our color vision and in the chemistry of available pigments, and these quirks appear across many different types of subtractive mixture (paints, inks, dyes or filters). Among the quirks that painters recognize early:

Dull orange or yellow mixtures, or mixtures of orange+black or yellow+black, produce qualitatively new unsaturated color zone (http://www.handprint.com/HP/WCL/color12.html#unzones) (**UCZ**) commonly called browns, ochres or green golds; similar colors do not appear in the green, blue or purple areas of the gamut.

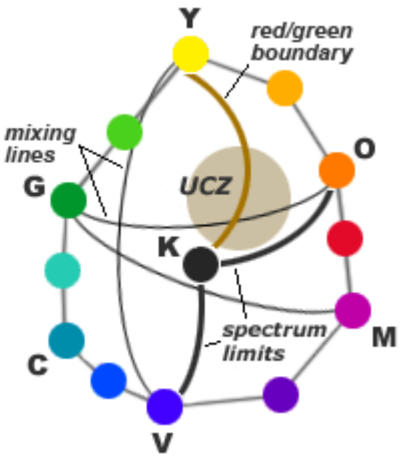
The unsaturated color zone is crossed by a **red/green boundary** that determines the appearance of dull hues; dull yellows on the green side of this boundary appear greenish (most raw umbers and all green gold or olive paints), dull deep yellows appoximately on the line (yellow ochre) appear greenish or yellow at light values and reddish or brown in dark values; and dull oranges or reds on the red side of the line appear reddish at all values (burnt umbers, burnt siennas, all iron oxide reds).

When projected into a color space, most mixing lines in most palette gamuts are not straight: most mixing lines are curved (http://www.handprint.com/HP/WCL/color15.html#mixlines). (For guidance on this point, see the

Some paint combinations, especially orange with cyan and magenta with green, can in the right proportions produce mixtures visually indistinguishable from pure gray or black; these are true **mixing complementary colors**.

Magenta+green (or red+blue green) mixtures are especially dark and often can substitute for a black paint on the palette.

Hues that correspond to the limits of the visible spectrum are approximately cadmium red deep and ultramarine blue. On the red side, the painter must understand the distinction between a spectrum vs. blue red (http://www.handprint.com/HP/WCL/IMG/RC/red.html), and know which pigments fall into each category: spectrum reds produce darker, less saturated violet or brown mixtures than blue reds. On the blue side, the red blue pigments (ultramarine violet BS PV15 (http://www.handprint.com/HP/WCL/waterv.html#PV15), ultramarine blue, indanthrone blue PB60 (http://www.handprint.com/HP/WCL/waterb.html#PB60) and cobalt blue) appear distinctly reddish in full strength paint applications but shift toward a middle blue hue in tints.



quirks in the color mixing landscape

21 Adjusting Color After Paint Has Dried. After the painter has becomes practiced in the manual task of mixing colors, and the perceptual task of matching colors, a larger problem comes into view, which is making all the colors within a painting consistent with each other. Color consistency is achieved by **adjusting existing colors** to minimize faults in single colors or improve the combined effect of them all.

Consistency can be judged in different ways, but the most common are (1) the colors represent a **convincing shadow series** of values, from light to dark; (2) the colors represent the common **effect of a tinted illuminant**, for example the reddish light of sunset or the greenish cast of indoor fluorescent light; (3) the colors **belong to the same nuance**, defined as very similar chroma and lightness across all hues, which is one of the simplest and most effective ways to create a "designed" color unity. Other criteria for color consistency are possible.

These criteria usually cannot be evaluated until the painting is largely blocked in, and the relative effect of all the color areas within the image can be judged as a whole. And this means color adjustments must be made to color after the paint has dried.

In what direction should colors be adjusted? The color adjustment goal is essentially defined by eye: the painter examines separately the lightness, hue and chroma of the color in relation to other colors, and the painter then decides what color adjustment is appropriate. The painter must decide whether the color must be (1) *lighter* or *darker*, (2) *hue shifted* toward a neighboring hue, (3) *more saturated* or *less saturated,* or (4) any combination of these.

These judgments define the manipulations necessary to produce the desired change:

Lightness. Colors that must be *lighter* generally must be lifted, by wetting and gently scrubbing the color area with a synthetic bristle flat brush, then blotting or wiping away the moisture with a white (undyed) paper towel. This operation is usually only successful with paints that are not staining (lift easily), and only for limited areas of paint (e.g., to add a highlight to a curving surface). Larger areas can be lifted by wetting the paint area and then lifting with firm strokes of a paper towel, but this produced an uneven and streaked color.

Colors that must be *darker* can be glazed with another layer of the same paint, but this typically increases the chroma of the color as it darkens it. To compensate, a small quantity of the complementary color must be added as well.

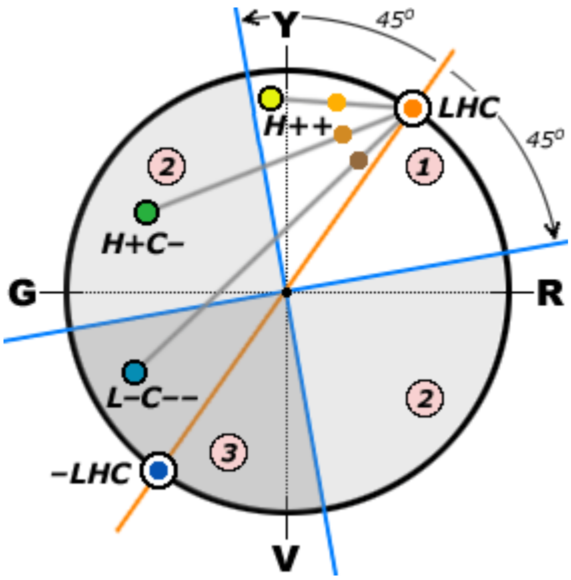
Hue. Colors that must be shifted in hue change toward a color neighbor to them on the hue circle. For example, a yellow may need to be either redder or greener. In general, only small hue shifts within about one quarter of the hue circle can be produced by mixture.

Larger hue shifts are possible, but the paint mixtures necessary to produce them will also have significant effects on the other two color attributes, typically darkening the hue and reducing the chroma of the color.

The most effective way to judge hue adjustments, especially when dealing with shadow series or the effects of a tinted illuminant, is to focus on the four cardinal artist's primaries (http://www.handprint.com/HP/WCL/palette4d.html) and determine whether the color is *too red, too yellow, too green* or *too blue (violet)*. This is a much more accurate approach than adjusting color using the traditional three "primary" colors (red, yellow, blue).

In particular, shadow appearance depends strongly on hue and chroma, not simply lightness (darkness). Shadows that appear too dark or dull usually can be subjectively lightened by shifting the color toward red; this must be done with a transparent, strongly tinting paint to prevent paint buildup. Shadows that appear too red can be cooled with minimal darkening by mixing with a green tint, and shadows that are too light can be darkened by mixing with blue tint. Observe that a very small hue and chroma change can have a very large impact on the shadow appearance.

Hue purity. Chroma or saturation is in principle a straightforward attribute to adjust, but the ability to adjust chroma is limited by the available selection of paints. On the one hand, any color that must be made *less saturated* can be glazed with any paint that is near the mixing complementary hue for the color. On the other hand, a color that must be made *more saturated* must be layered with a more intense paint of the same hue ... but most watercolors are only moderately saturated to begin with (so the potential chroma increase is small), and in many parts of the hue circle (greens, greenish blues and purples) lightfast high chroma paints simply are not available.



simultaneous color changes across
hue circle mixing distances

For any specific color we want to change (shown as **LHC**) above, the mixing complement of that color (**LHC**) is approximately opposite it on the hue circle. If we then define a quadrant centered on the change color and its mixing complement:

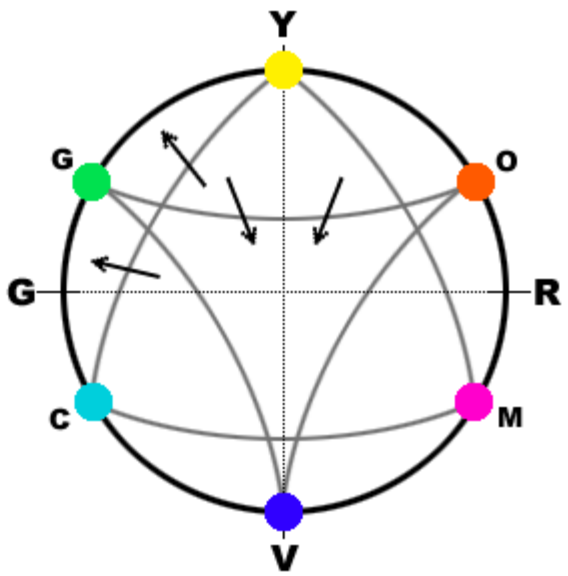
Mixing the change color with any other saturated paint in its quadrant on the hue circle (**1**) will shift the hue with little effect on the chroma (**H++**).

Mixing the change color with any paint in the opposite quadrant of the hue circle (**3**) will have little effect on the hue but will strongly reduce the chroma (**C**) and significantly reduce the lightness (**L**) for medium light valued colors.

Mixing the change color with any saturated paint in either of the two remaining quadrants of the hue circle (**2**) will moderately shift its hue and will significantly reduce its chroma (**H+C**).

These guidelines apply to any change color, regardless of its hue: the orange line can be rotated like a compass needle, and the same relationships apply.

Note that the diagram (above) shows the mixing lines as straight lines, which we have already found is not generally true of a gamut space. The mixing space quirks that produce need to be taken into account when anticipating the effect of color mixtures on adjusted color.



curved mixing lines around a subtractive gamut

As a rule of thumb, mixing lines between the **subtractive primaries** (magenta, yellow or cyan) tend to bow outward: they produce a *smaller chroma loss* than would be expected by the distance between them on the hue circle. This is because subtractive cyan, yellow and magenta colorants have high lightness or a broad area (http://www.handprint.com/HP/WCL/color5.html#idealsub) of high reflectance. These broad areas overlap when the paints are mixed, which sustains the chroma of their mixtures.

Mixing lines between the **additive primaries** (orange, green, violet) tend to bow inward: they produce a *larger chroma and lightness decrease* than would be expected by the distance between them on the hue circle. This is because most subtractive colorants in these hues have a **narrow area** of high reflectance and, in both orange and violet pigments, are highly saturated. This produces narrow areas of high reflectance that do not overlap when the paints are mixed, which subdues the chroma of their mixtures.

22 A Vocabulary of Paint Attributes. As the student makes more paintings he can be introduced to the other paint physical attributes important to watercolor painters, which should be explained in terms of the basic ingredients (http://www.handprint.com/HP/WCL/pigmt1.html#ingredients) in watercolor paints:

transparency, or the "show through" of paper color or other paint color that is under the paint, is caused by small pigment particle size, high tinting strength, low pigment load and a low refractive index.

lightfastness, or endurance without fading under prolonged light exposure, is primarily a chemical attribute of the pigment that is also affected by pigment particle size (smaller particles are less lightfast).

staining, or resistance to removal by scrubbing or blotting, is caused by small pigment particle size, low proportion of gum binder in the vehicle, added dispersants or humectants, and absorbent or lightly sized paper.

lifting, or the tendency of the paint to redissolve when a new layer of paint is applied over it, is typically due to (a) large particle size and/or (b) a high proportion of gum arabic (or other hydrophilic ingredients) in the vehicle.

specific gravity, or the weight of pigment in water, is revealed by how quickly the paint sinks to the bottom of a container when mixed with pure water or how quickly the paint separates when mixed with a second paint (for example, a phthalocyanine paint with a cadmium or cobalt paint).

granulation, or the visible grainy texture of the paint, is due to large paint particle size and/or increased dispersant in the paint vehicle.

flocculation, or the appearance of clumping or mottling in the dried paint, is due to slight electrostatic attraction among dissolved pigment particles that appears in diluted paint applied as a juicy brushstroke or wash.

dispersion, or the tendency of the paint to expand rapidly when applied to wet paper, due to small particle size and dispersant in the paint.

the tendency of the paint to form a *backrun* when rewetted after it has partially dried, is increased by small particle size or added dispersant, when water or paint are added to paper that has dried to a satin wetness (http://www.handprint.com/HP/WCL/wet1.html#3).

the tendency of the paint to *bronze* when applied as a thick mixture, caused by a high proportion of binder to pigment and a low proportion of plasticizer to binder in the paint.

Paints are of different types:

Much confusion can be avoided if you keep words and meanings straight. Take care to distinguish between *hue* and *color, pigment* and *paint,* and *paint* and *color:*

hue is the name for a location on a hue circle or color circle, or a basic color category that does not depend on lightness or chroma; *color* refers to a surface, light or visual sensation that can be described by all three colormaking attributes (http://www.handprint.com/HP/WCL/color3.html#colormaking) hue, lightness and chroma. (Pink and maroon are both red *hues;* maroon is a dark, dull, red *color*.)

pigment is an insoluble substance that creates color in the way it absorbs and reflects light; *paint* is a mixture of pigments with other substances that allow the pigment to be applied with a brush and that bind the pigment to the support once the paint has dried.

paint is a physical substance; *color* is a sensation or perception in the mind; artists buy and mix paints, not colors.

Keeping words straight helps the painter distinguish between three categories (http://www.handprint.com/HP/WCL/pigmt6.html#colors) of commercial watercolor paints:

single pigment paints (paints that contain only one type of pigment)

imitation or *hue* paints (which imitate the color of an expensive or fugitive pigment with cheaper or more permanent pigments), and

convenience mixtures of two or more pigments that painters would otherwise have to mix for themselves (green, purple and dark neutral colors in particular).

In all cases, the CI names will clarify whether the paint is a single pigment paint, imitation or hue paint, or a convenience mixture. Without the CI name, the paint manufacturer's **marketing name** (the "color name" of the paint) tells you nothing about what is actually in the paint, or its color. Artists do better when they examine the *ingredients* in paints, rather than choose paints by their *colors*.

23 How to Examine Paint Transparency. Traditional watercolorists prize the **transparency** of paints, a term they use for weak *hiding power*. Transparency is actually a different paint attribute, one that is also useful to evaulate.

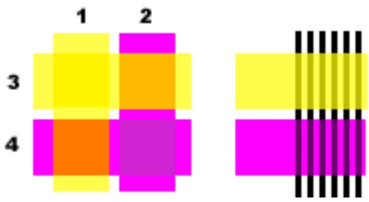
Most painters test the hiding power of palette paints by painting overlapping stripes in sequence, so that each paint is painted over itself and under and over all other paints; in this test the more opaque paint will (1) change color less when painted over itself, and (2) dominate any color it is painted over. In the example at right, the magenta and yellow stripes are painted in numerical order, and the yellow paint is less transparent (more opaque) than the magenta.

This method is inconclusive, as dark paints or strongly tinting paints can also seem to "hide" the paints underneath them. The more accurate test is to apply a single layer of the paint over an area of indelible black lines (for example, drawn on watercolor paper with a wide tip Sharpie indelible pen): the difference in appearance between the painted and unpainted lines is a direct, accurate measure of paint opacity or hiding.

In contrast, a *transparent* paint will seem to disappear if painted on a relatively nonabsorbent black ground (http://www.handprint.com/HP/WCL/pigmt3.html#blackfield), such as a sheet of black acrylic, bristol board, mat board, or the black paper used to cover new Arches (http://www.handprint.com/HP/WCL/paper2a.html) watercolor blocks. Paints that do not appear transparent by this test, but that are also low in hiding power, typically contain significant amounts of laking substrate, additives or fillers.

In practice, the "transparency" of a paint mixture is primarily determined by the *dilution* of the paint in water: the greater the proportion of water to paint in a mixture, the more transparent the finished color will be. Transparency often appears greater for pigments with higher tinting strength, because the paint produces a more powerful color at higher dilution. (To compensate, most manufacturers "predilute" these dominant pigments with a larger quantity of vehicle.)

If all paints are diluted by the same amount, then transparency depends primarily on the particle size (http://www.handprint.com/HP/WCL/pigmt3.html#particlesize) of the pigment and its ability to refract light (http://www.handprint.com/HP/WCL/pigmt3.html#refractiveindex).



two evaluations of paint hiding power

applying one paint over another is less accurate than applying a single paint over a black/white pattern

evaluation of paint transparency

a completely transparent paint will seem to disappear on a black ground

24 How to Examine Paint Permanence. Adequate paint **lightfastness** is essential to the permanency of watercolor paintings. Students should learn the basic logic and procedures of lightfastness tests (http://www.handprint.com/HP/WCL/pigmt9.html). These expose standard samples of paint to prolonged

sunlight or artificial light exposure, while masking part of the sample from light; after an appropriate exposure period, there is a visible difference between the exposed and masked paint areas in *impermanent* or *fugitive* paints. The samples below illustrate the most common problems that a watercolor painter should be aware of.

examples of common watercolor lightfastness issues

(top row) alizarin crimson (PR83), rose madder genuine (NR9), naphthol red (PR170), naples yellow hue (+PW4), rhodamine violet (PV1); (bottom row) potassium cobaltinitrite (PY40), convenience green mixture, bismuth yellow (PY184), quinacridone magenta (PR122), dioxazine violet (PV23)

the pigment **alizarin crimson** (PR83 (http://www.handprint.com/HP/WCL/waterr.html#PR83)) has proved to be fugitive in every paint lightfastness test to examine it over the last 140 years; artists who insist on using or recommending it, especially by saying that "they see no problem with it in their own work," only flaunt their professional ignorance and contempt for the art market.

the pigment **rose madder genuine** (NR9 (http://www.handprint.com

/HP/WCL/waterc.html#NR9)), now only available from two paint manufacturers, is similarly impermanent.

several kinds of orange, red or brown naphthol pigments (http://www.handprint.com/HP/WCL/pigmt1d.html#naphthol), such as this **permanent red** (PR170 (http://www.handprint.com/HP/WCL /waterr.html#PR170)), have well documented lightfastness problems: many artists avoid all pigments in this category.

hue or convenience mixtures that include a white pigment, such as this sample of a naples yellow hue (http://www.handprint.com/HP/WCL/watery.html#naples) (made with zinc oxide white, PW4 (http://www.handprint.com/HP/WCL /waterw.html#PW4)) show a consistent tendency to whiten and desaturate.

nearly all "brilliant" or "fluorescent" paints are augmented with dyes, as in this "brilliant purple" paint containing **rhodamine violet** (PV1 (http://www.handprint.com/HP/WCL/waterv.html#PV1)), and are completely unreliable.

the pigment **potassium cobaltinitrite** (sold under the generic name *aureolin*, PY40 (http://www.handprint.com/HP/WCL/watery.html#PY40)) fades and discolors often enough that it should be avoided.

some **convenience green mixtures** (such as this sap green made with phthalocyanine green, PG7 (http://www.handprint.com/HP/WCL /waterg.html#convenience)) are unreliable because either the yellow pigment fades or because the yellow and blue or green pigments fade unevenly.

the last three examples illustrate the fundamental unreliability of published paint lightfastness ratings, including paint manufacturer and ASTM lightfastness ratings, as an assurance of paint lightfastness. The first is a sample of watercolor made with **bismuth yellow** (PY184 (http://www.handprint.com/HP/WCL/watery.html#PY184)), which has always proved to be very permanent in lightfastness tests but here has discolored for some reason, possibly contamination with impurities during manufacture. The last two examples show pigments routinely condemned as impermanent in published paint guides, but which in my lightfastness tests have either proved to be consistently lightfast (**quinacridone magenta**, PR122 (http://www.handprint.com/HP/WCL/waterc.html#PR122)) or have turned out lightfast in the paints from some paint manufacturers but not others (**dioxazine violet**, PV23 (http://www.handprint.com/HP/WCL/waterv.html#PV23)).

Lightfast watercolor paints on archival papers are as durable as paintings in oil or acrylic; impermanent materials lower market confidence in watercolor paintings and depress the prices all artists can ask for them as investment artworks. Contemporary watercolor artists are increasingly careful to **avoid fugitive or impermanent paints** which includes all 19th century organic pigments (alizarin crimson, rose madder, carmine lake) and many convenience (premixed) greens and purples. Mindful of the problems described above, they test their own paints, inks or colored pencils to confirm manufacturer quality standards.

25 How to Examine Paint Staining. Watercolors provide the painter with a unique quality of impermanence: most paints can be redissolved by wetting and gently brushing with a stiff bristle synthetic fiber brush, then lifted by blotting the dissolved paint mixture with a paper towel.

Staining is typically defined as the difficulty with which a paint is lifted from paper, or the quantity of residual color remaining in the paper after lifting has been completed.

Paint **staining is significantly affected by the type of paper used**, since by definition lifting from paper is the way staining is evaluated. Paint that is staining on one type of paper can be nonstaining on another type. The paper attributes that most affect staining are: the amount and type of internal and external sizing (paper absorbency), surface finish (rough vs. hot pressed), and pulp density or porosity.

The tendency of watercolor paint to stain paper really has two different causes, which can be called *electrostatic staining* and *absorption staining*.

Electrostatic staining appears in paints that stain plastic or ceramic palettes or mixing dishes. These hard surface stains do not easily dissolve or rub away when wetted, and in extreme cases can only be cleaned with a solvent or nonabrasive cleaner (Bon Ami or 409); the staining seems aggravated when a paint mixture is left to dry out on the surface. The cause here is an electrostatic charge in the pigment that binds to material. This is found in several synthetic organic pigments, including dioxazine violet, the phthalocyanines (blue, turquoise or green), many quinacridones, and some pyrrole reds or oranges. As a rule, electrostatically staining paints are *always highly staining* on all types of paper and regardless of how the paint has been applied or how much the paint is diluted.

Absorption staining appears in paints that are absorbed or penetrate into the spaces between paper fibers, where they cannot easily be dislodged by surface scrubbing or bind weakly to the cellulose fibers. These are typically paints with small pigment particle sizes, especially paints that have been formulated with some dispersant, and include most synthetic organic pigments of all hues, the cadmium pigments, chromium oxide green, iron blue, venetian reds or burnt siennas classified as PR101 (http://www.handprint.com/HP/WCL/watere.html#PR101), and carbon black. Absorptively staining pigments are noticeably less staining when applied to fresh paper with good surface and internal sizing, to hot press or dense papers, or when applied as a diluted paint mixture or as a glaze (new layer of paint) on top of several layers of paint already on the paper.

Pigments with no electrostatic charge and with large pigment particle sizes lift easily under almost all conditions; these include most cobalt pigments, burnt siennas classified as PBr7 (http://www.handprint.com/HP/WCL/watere.html#BS), and most other iron oxide pigments (such as yellow ochre, raw umber or burnt umber).

26 A Vocabulary of Paper Attributes. As the source of white (or "light") in a watercolor painting, which cannot be mixed from other colors (paints) but contributes to the color of all other mixtures, watercolor paper (http://www.handprint.com/HP/WCL/paper1.html) is effectively a "primary" color in watercolor painting, just as white paint is a primary palette color in oil or acrylic painting.

Paper is also the support for the work, and intimately absorbs the pigments the artists puts on the sheet: unlike oil paintings, watercolors cannot be relined. The durability or permanence of the sheet must also be a primary consideration in choosing papers for collectible artworks.

Paper has very different *presentation* and *quality* attributes than paints, and the painter needs to be familiar with these and their relative importance to the finished quality of a painting.

Presentation Attributes

color is typically the white of cellulose fibers, sometimes with a slight warm tint; "bright white" papers should be avoided as these contain *optical brightening agents* (impermanent dyes) that fluoresce in blue wavelengths, neutralizing any excessive yellow tint in the paper. (The obvious question: why was the pulp too yellow to begin with?)

basis weight, quoted as the weight of a single square meter sheet of paper in grams

(grams per square meter or *gsm*) distinguishes thin or fragile papers from thick papers; the typical range for watercolor papers is 300 gsm to 600 gsm; papers above 600 gsm are board weight. Fragile papers tend to warp more after repeated wetting with water or paint and to be somewhat more absorptive.

finish, the surface texture of the sheet, is either rough (**R**, produced by air drying the paper), cold pressed (**CP**, the sheet dried in stacks, separated by felt blankets), or hot pressed (**HP**, the sheet is calendared between hot rollers). (English manufactured **NOT** papers are cold pressed papers that are "not" hot pressed.)

Hot pressed papers best display subtle granulation effects, especially in dilute color mixures; they are less absorptive and encourage water marks (backruns) in wet paint; rough papers have a surface texture that accents brush textures and coarser granulation effects. Note that there is amazing variety across paper manufacturers in the same nominal finish, and the CP finish in one brand of paper may be similar to the R finish in another. Look at the paper surface, not at the label.

sizing, traditionally gum arabic but now often a synthetic carbohydrate such as *Aquapel,* is a coating applied to cellulose to reduce or slow the absorption of water and paint inside the paper or the "creep" (capillary action) that diffuses paint beyond the brush mark. *Pulp sizing* is added to the furnish before the paper is cast; surface sizing (or "tub" sizing) is added to the surface after the sheet has dried. *Waterleaf* papers contain no sizing at all.

watermark is an area of greater compression or thinning in the paper pulp that permits more light to shine through, producing a pattern. Normally a brand name or brand symbol and traditionally an embossing figure woven into the wire handmaking paper mould, it is produced on web papers by a rubber stamp. Despite widespread belief, the watermark cannot be used to choose the higher quality side of the paper; common pratice is to orient the sheet so that the watermark is in the lower (preferrably right) corner and "reads right" (is not reversed).

Quality Attributes

manufacture, the method used to create the paper, can be either handmade, mouldmade, or machinemade. Machinemade papers are typically for the mass market and will curl cylindrically when soaked; mouldmade and handmade sheets tend to *cockle* or warp unevenly when soaked. Although handmade sheets are often considered the acme of papermaking quality, many high quality sheets are mouldmade, and some low quality sheets are handmade: judge the paper, not the manufacture.

furnish, the materials used to manufacture the paper, include cotton or linen fiber, flax, and wood pulp. The highest quality papers are usually (not always) 100% cotton or 100% linen; *rag* means the cellulose comes from whole fabric or thread *linters* are feltlike pads of lint (much shorter fibers) shredded off during fabric manufacture. As a simple and infallible test, a piece of pure cotton or linen cellulose paper will leave a white, whispy ash when burned: a black or brittle ash indicates other ingredients (wood pulp cellulose, synthetic fibers, excessive chemicals) are present.

acidity or pH, which affects the longevity of the paper; as acidic papers are less durable it is very desirable to have a pH that is neutral or slightly alkaline (pH = 7.5 to 10). *Acid free* does not refer to the pH of the paper but means the pulp was not chemically treated during manufacture.

buffering or "alkaline reserve" refers to calcium carbonate or an eqivalent chemical added to the furnish to stabilize the pH of the paper after it is manufactured. In some cases this is also done to neutralize the acidity built up by manufacturing additives introduced during pulping.

lignin, a component of wood fibers, is very detrimental to paper durability and the major reason newsprint turns brown in sunlight; "lignin free" simply asserts that nearly all the lignin has been removed from the furnish. Lignin contributes to a black paper ash. "Wood free" or "wood sulfite" papers are manufactured from chemically treated wood pulp; wood cellulose (sometimes mislabeled *alpha cellulose*) is 10 times weaker than cotten or linen cellulose.

fold strength is shown by how well a paper can tolerate being folded back and forth along the same crease without breaking, and *tear resistance* is shown by the amount of effort required to tear the sheet along a fold. Rag papers usually have greater fold strength and tear resistance, and the tear will expose many straggling individual strands of paper fiber; linter papers are weaker, and the tear will appear very even and fuzzy.

archival quality, as accepted in the publishing industry, is a shorthand manufacturer assurance that the paper contains less than 1% lignin, has a pH greater than 7.5, has at least 2% calcium carbonate content, and has a tear resistance (defined mechanically) that is sufficient for book publishing. The term is used far too loosely in the art materials market; Yupo even uses "archival" to describe their printable plastic sheets, which embrittle with age and have nothing to do with lignin, alkaline reserves or cellulose content.

rattle is the sound one sheet of the paper makes when held by one corner and shaken vigorously. A "bright" metallic rattle indicates the pulp was completely macerated (mechanically pounded) and well compressed during manufacture, a "dull" or muffled, woody rattle typically indicates a spongier pulp, less compression of the pulp, wood ingredients, or linter fibers.

The watercolor painter should know these attributes well enough to assess them in new papers and to understand how each affects the quality and appropriate pricing of a finished watercolor painting.

27 Practice, Play & Improvisation. At this point the painter has enough practical and conceptual knowledge to guide her own color exploration and mastery of watercolors. Learning color through paints is at an end, and color now becomes the framework for a personal painting style.

Three attitudes help to sustain this individual path: *pratice, play & improvisation*.

Practice implies patience and tolerance of "failures", which are often just paintings that take longer to complete. Difficult paintings should be set aside and returned to after a few weeks or months; difficult paintings sometimes blossom with a little perseverance. And some paintings are worth trying two or three times. Don't be frightened away from a struggle.

Play implies that the struggle is not carried to extremes, and that the struggle is sometimes with ourselves, with our fears or high expectations or inner critic or comparison to other painters' works. Play means that you set these things aside and focus on the painting process for the enjoyment and stimulation it will always provide if you let it.

Improvisation implies that you let go of dogma, rules, habits and control; water is your willful and sensuous partner, the color landscape is always a bit mysterious, and the gamut of a well balanced palette is an inexhaustible source of new color effects. Improvisation also implies that you produce both small pieces, where the costs of disappointment are small, as well as large works, where your skill can be put on full display.

All these add up to a commitment that lasts for more than a few months. Take your time, enjoy, follow your whims; the journey is the destination. Only long experience with mixing paints lets a painter anticipate color mixtures; only the experience of making many paintings lets the painter use color confidently and with feeling.

Study is the teacher of knowledge, but play and improvisation are the teachers of skill. Make as many paintings as you can, and let yourself enjoy the process of painting, and your progress will follow a natural and unique course.

Good luck!

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