transparent a particle will appear. The high refractive index of Cadmium Yellow and Titanium White, for instance, is almost solely responsible for their tremendous hiding power and sense of opacity, while Zinc White and Hansa Yellow appear more transparent because their refractive indexes are considerably closer to that of an acrylic polymer. Because dark pigments with low refractive indexes, such as the Phthalocyanines, do not scatter much light, their hiding power resides almost completely in their ability to absorb light, the pigment loading, and the thickness of the film.

The other aspect of particle size has equally dramatic consequences on both scattering and tinting strength. As a particle becomes smaller it scatters light more effectively until a certain optimal size is reached, after which this aspect begins to drop off sharply. As one continues further below this threshold, the pigment particle grows increasingly transparent while simultaneously reaching a maximum of tinting strength. Here is where the magic of the Transparent Iron Oxides reside, as the normally opaque iron oxide pigments are manufactured to such small particle sizes that they become wonderfully translucent and far more effective in glazing and the production of cleaner, higher chroma tints. Titanium White, on the other hand, is carefully manufactured to optimize its particle size for maximum light scattering, and hence opacity. In fact, a one centimeter wide crystal of Titanium Dioxide is completely transparent, and it is only as the crystals get smaller that scattering becomes dominant and we sense the pigment as inherently 'white'; an effect similar to the whiteness of finely ground glass. Should the Titanium Dioxide be ground even further down to a nano-particle scale, it would actually become completely transparent, a feat that seems almost magical given how strongly we associate opacity with Titanium White.

Purity and Uniformity

Differences in the chemical purity of a particular pigment, as well as the uniformity of its shape and size distributions, are responsible for still other quirks of coloration. For example, natural earths owe their particular flavors and nuances to varying amounts of trace elements, such as manganese oxide, silica, alumina and clays, as well as their wide assortment of particle sizes. While this accounts for many of their prized undertones, and explains why particular regions in the world become coveted for their mined ochres, siennas, and umbers, it is also the reason why these colors are generally weak tinters and lower in chroma than the parallel range of synthetic oxides. Also, because they are mined, these pigments have a wide lot to lot color variation depending on the level of impurities in the next shovel full. Ultramarine Blue presents another example; one of the earliest synthetic pigments, it is richer and more saturated than the genuine Lapis Lazuli it replaced, which as a mined rock always came with impurities of calcite, sodalite, and pyrite, that muted its tone.

THE PHYSICAL PROPERTIES OF PAINT

Film Thickness

As most artists know, colors do not necessarily stay the same through thick and thin. In thick films of densely packed pigment, the masstone is dominant and the color will appear more saturated and deeper. As the film becomes thinner, the undertone becomes more pronounced and the overall color can appear more transparent, lighter in value, and sometimes higher in chroma as well, assuming the underlying substrate is very light in tone. These effects are ultimately caused by having an increased amount of light reflected from both the pigments and the underlying substrate in the form of backscattering.

Pigment Load

Beyond film thickness, simply altering the pigment load or density in a paint film can markedly change the perception of a color. For example, in a film of densely packed translucent pigments, much of the interior scattering and transmittance of light can be lost through subsequent and repeated absorption, and one primarily sees just the reflected light coming from the surface. This reduction in light reads as a deepening in hue and a reinforcement of the dominant absorption band. As pigment load is decreased, and light begins to penetrate through the film, the interplay of scattering and absorption has a larger impact on the overall color. One can imagine a similar effect if placing identical sheets of stained glass on top of each other, one after another. As the pile grows thicker, the color will get increasingly deeper and more saturated.

At its most extreme, the spectral reflectance curve can change considerably as more and more light is able to penetrate deeply into the material. This phenomenon can be seen in such transparent colors as Green Gold and Nickel Azo Yellow, where a dramatic difference emerges between the mass and undertone, as well as a subtler shift in spectra for Phthalocyanine Blue G/S.

Sheen and Surface

Whether a surface is glossy or matte, smooth or textured, will ultimately impact a color's expression as well. As a paint film becomes glossier and smoother, there is less scattering of light at the surface and more penetration and absorption of the light by the pigments themselves. This causes darker colors to typically appear deeper and more saturated when they have a gloss sheen, and conversely, appear to lighten if matte; not unlike the phenomenon of removing a darker colored stone from the bottom of a riverbed and watching the seemingly rich color dissolve before ones eyes with the evaporation of the water.

CASE STUDIES

The spectral data used in the following case studies was obtained using a Minolta® Spectrophotomer. Samples were cast as 10 mil drawdowns on lacquered cards, with each color represented both at full strength and mixed with varying percentages of GOLDEN Regular Gel (Gloss) or Titanium White. Many of the graphs used in this article are spectral curves, which might be unfamiliar to many artists as they are not that common outside of laboratory settings. The easiest way to understand them is simply as showing the amount of light that is reflected from the surface for each wavelength in the visible spectrum. The more that is reflected, the higher the curve will be at that point. To make the readability a little easier, along the top of each graph we include markings showing the approximate range for each band of color, running from Violet through Blue, Green, Yellow, Orange, and Red. The x-axis, running along the bottom, is marked with the actual wavelengths themselves.

WHEN COLORS COINCIDE

Phthalo Blue (GS) Mixed 1:3 with Hansa Yellow Medium and Cadmium Yellow Medium

The Hansa Yellows sit across from the Cadmiums like a row of twins arriving late and uninvited to a family dinner. Contrary to many notions these are not the poor substitutes for the 'real' thing, but truly flushed with their own sense of flash and purpose within the painter's toolbox. The Hansas might not have the opacity of the Cadmiums, but their transparency allows them to be an essential ingredient for transparent glazes, deep greens, and composite blacks. For all the brash and brawn of the Cadmiums, the Hansas speak in their own bright voice.

A good way to experience these subtleties is to watch how the two colors impact various mixtures. With a Phthalocyanine Blue or Quinacridone Magenta, for example, Cadmium Yellow Medium creates dense lighter-valued tints with a sense that white has somehow strayed into the mix. In the accompanying graph (Graph 1), notice how it produces a sharp spike in value after 500nm, and an elevated reflectance throughout the oranges and reds. With Hansa Yellow Medium, on the other hand, the saturation of Phthalo Blue (GS) is largely preserved and the hue is simply shifted towards green with a minimum increase in value. What is not as well shown here is the fact that the translucency is held onto as well, the mixture remaining ideal for glazing and developing other rich, dark greens.

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SEEING THROUGH OPAQUE PIGMENTS

This section begins with pairs of synthetic and natural iron oxides whose differences revolve almost entirely around particle size, with the synthetic oxides being exceptionally small when compared to the usually chunky, larger-scaled pigments of natural earth colors. As mentioned earlier, when particles grow smaller not only does the total surface area increase rapidly, but their ability to scatter light diminishes as well. With scattering held to a minimum, the pigments' interaction with light is solely through absorption and reflection, which both maximizes their tinting strength and increases their translucency. As a result, the synthetic oxides will often be the preferred choice when needing brighter mixtures and cleaner glazes, while the more standard earths can provide a wonderful opacity and density when relying on their masstone.

Yellow Oxide (PY42) / Transparent Yellow Iron Oxide (PY42)

Yellow Oxide and Transparent Yellow Iron Oxide have differences that are a little obscured, perhaps, by their identical Color Index designation as PY42. In fact, many artists assume far too often, that pigments with matching Color Index names are unvaryingly the same. But nothing could be further from the truth, especially if reaching for a yellow earth for glazing or to use in tints or mixtures. And some differences can be seen fresh out of the tube, where the Yellow Oxide starts out brighter and very opaque, while the Transparent Yellow Iron Oxide has a much deeper, almost Raw Sienna masstone and is one of our most transparent colors. From there the differences grow, all tied to the singular issue of particle size more than anything in their chemistry.

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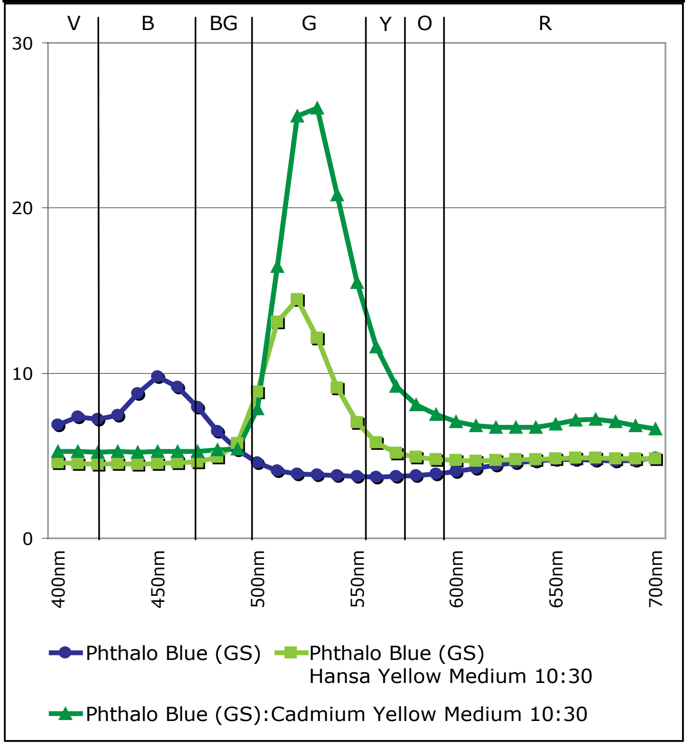
The accompanying graph (Graph 2) traces changes in Chroma when varying amounts of gel are added. As one can see, Yellow Oxide remains relatively flat throughout, increasing only slightly as more and more gel is added. No matter how transparent you make it, Yellow Oxide remains a muted color with moderate saturation. On the other hand, while Transparent Yellow Iron Oxide starts appreciably lower in overall Chroma, it actually increases dramatically in saturation as gel is added, eventually surpassing Yellow Oxide at the 1:1 mark and continuing to rise even further. Paradoxically, perhaps, the color grows in brilliance as it is extended with gel, providing proof – should one ever be needed – that it is the better choice for creating luminous glazes.

GRAPH 1: Phthalo Blue (GS) Mixed 1:3 with Hansa Yellow Medium and Cadmium Yellow Medium



GRAPH 2: Yellow Oxide and Transparent Yellow Iron Oxide Mixed with Regular Gel (Gloss)