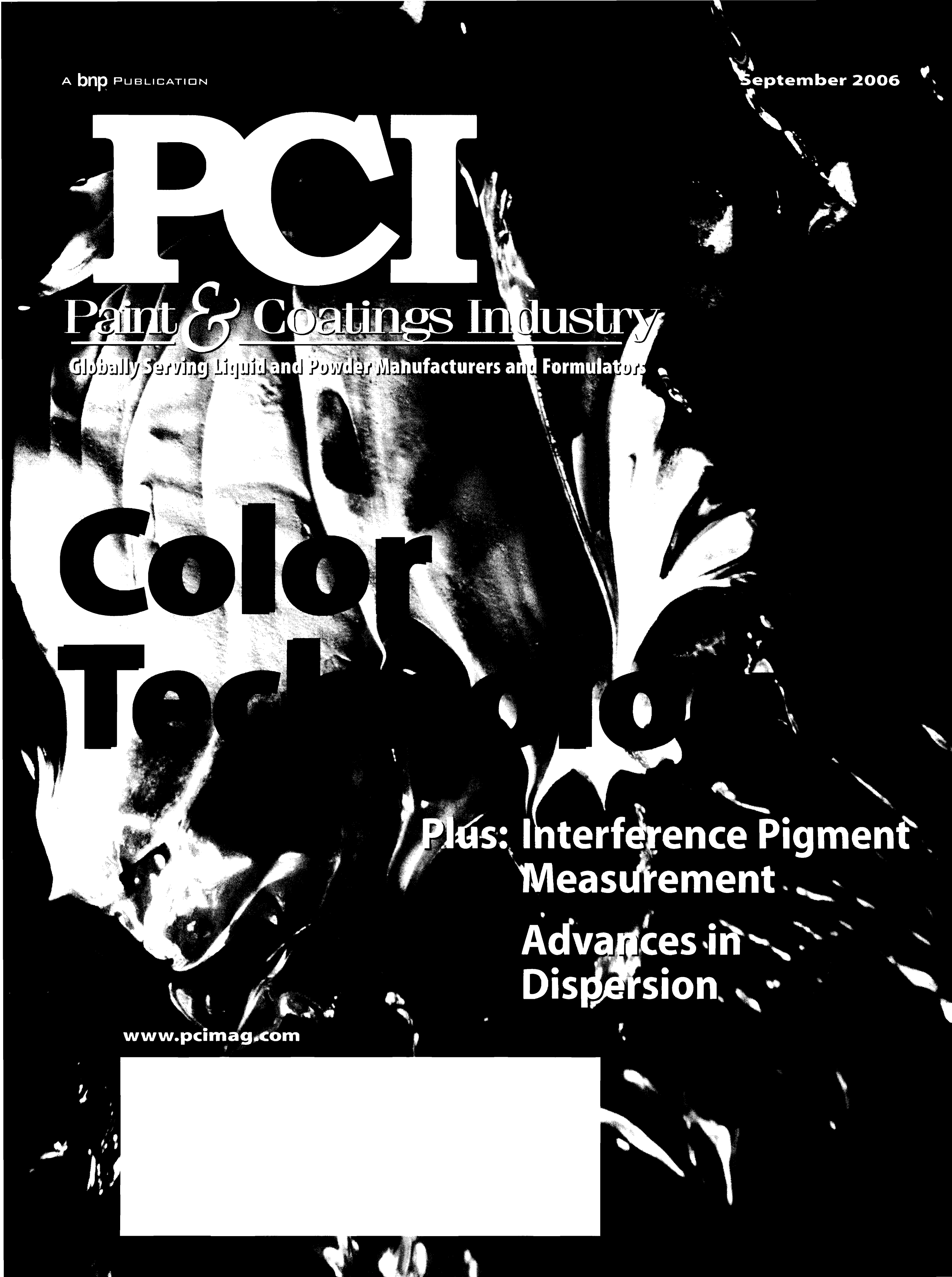

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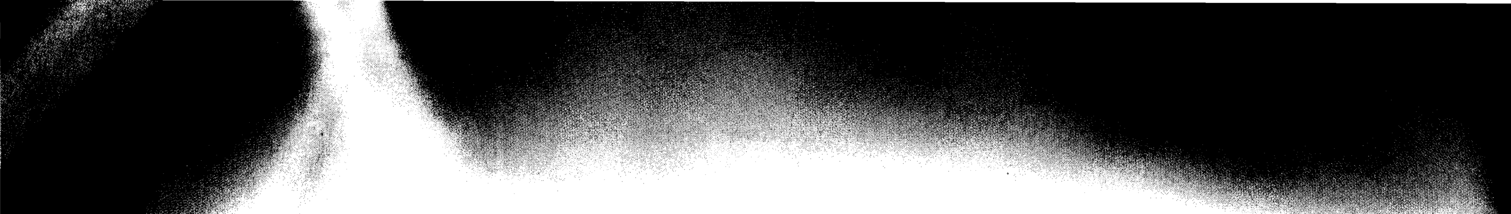


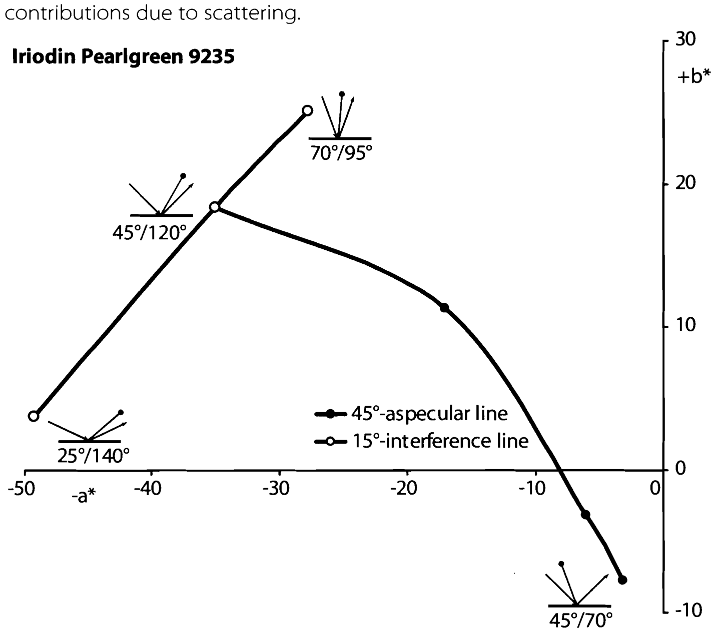
Man versus

Visual and Instrumental Characterization of Interference Pigments

The objective of colorimetry is arriving at a characterization of color and color fidelity that is as objective as possible. It is supposed to generate the linkages between physical measurements and physiological sensory stimuli, independent of any subjective factors. The fact that purely visual judgments yield results differing from instrumental characterizations, particularly in the case of interference pigments, is due to differing circumstances, rather than the nature of the subject matter.

Regardless of whether one works in the pigment, paint or automotive industry, those who deal with interference pigments cannot avoid contending with their physical and optical properties. Unfortunately, that is frequently forgotten and ignored due to a lack of knowledge of, and experience with, that particular type of pigment. Visual and instrumental characterization of a pigment's optical properties are equally important, since the color that results will vary with the angle at which light is incident on it. Together with the viewing angle, that angle yields a precise representation of the interferences involved.

Figure 1 | Interference pigments are individualists. Measurements at various angles of incidence with the same difference between the angle of specular reflection and the viewing angle yield their characteristic interference line. Results of measurements at a constant angle of incidence and various difference angles yield their aspecular line, which largely represents contributions due to scattering.



Measurements on a pigment that are made while varying the incidence from a flat angle at 25°, through the conventional at 45° to a steep angle at 75°, while maintaining a constant 15° difference between the respective angles of specular reflection and viewing, yield a characteristic interference line for that particular pigment and angular difference (Figure 1). The designations of angles employed here are referred to a graduated semicircular arc covering the angular range 0°-180° residing atop a test panel, where the plane of the arc is normal to the surface of the test panel, in which case, the normal to the panel's surface will coincide with 90°. Illumination at 45° will yield a specular reflection at 135° (cf. the endnotes). The measurement results for any other angle of illumination will be stable and plausible, provided that the difference between the angle of specular reflection and the viewing angle remains constant at 15°. Employing lesser differences in those angles could cause discrepancies to arise, particularly in the case of basecoat/clearcoat systems. Employing greater differences in them could cause light scattered by interference pigments, and admixtures pigmented with them, to be included in the results obtained.

Interference pigments generally exhibit a shift in their reflectance maxima toward shorter wavelengths when illuminated at flatter angles. For example, the reflectance peak of a conventional pearl-green pigment will be shifted from the yellow-green to the blue-green spectral range, while that of a red pigment will be shifted from the blue-red to the yellow spectral range (Figure 2). Those statements apply to both the pigments alone and their admixtures with both colored and aluminum pigments. The method involving varying the angle of illumination while maintaining a constant difference between the angle of specular reflection and the viewing angle thus provides ideal means for identifying and characterizing interference

By **Werner Rudolf Cramer** | Muenster, Germany

pigments. Every interference pigment has its own individual set of optical properties that it retains, even in admixtures.

Geometries other than that mentioned above, including those where the angle of illumination is held constant and the difference between the angle of specular reflection and the viewing angle is varied, are employed in arriving at complete characterizations of the optical properties of interference pigments. The results of such measurements yield aspecular lines that are largely attributable to scattered light and characteristic of the particular angle of illumination employed. Illumination is usually at 45°, and measurements are taken while the difference between the angle of specular reflection and the viewing angle is varied from 15° to 25°, 45°, 75° and 110° (aspecular angle).

Such geometries are currently employed in industry, although interferences cannot be acquired for the reasons stated above, where various interference pigments or admixtures of them with other pigments may well yield nearly identical aspecular lines (Figure 3). Delivery conditions thus cannot be formulated based on such measurements in the case of interference pigments and paints pigmented with them.

Visual Characterizations

In the case of visual inspections, inspectors normally stand opposite a laboratory window and point a test panel at the window. They initiate their inspections by holding a test panel flat against their stomach or chest such that they see light from the window reflected in the panel. Without shifting their location, they then tilt the panel upward or downward. If we examine the metrological geometries for those motions, we arrive at the following procedure for checking test samples.

At its initial orientation, the test panel will be illuminated at an angle of incidence of 75° and viewed at an angle of 105°, the angle at which light coming from outdoors will be specularly reflected by the test panel. If the panel is then tilted downward 5°, the angle of illumination will change from 75° to 80°, the angle of specular reflection will change from 105° to 100°, and the viewing angle will change from 105° to 110°. The angular relationships between the illumination (light coming from outdoors), the observer (the

Figure 2 | The colors of interference pigments will typically shift toward shorter wavelengths when illuminated at flatter incidence, where an interference red will become more yellow, and an interference green will become more blue.

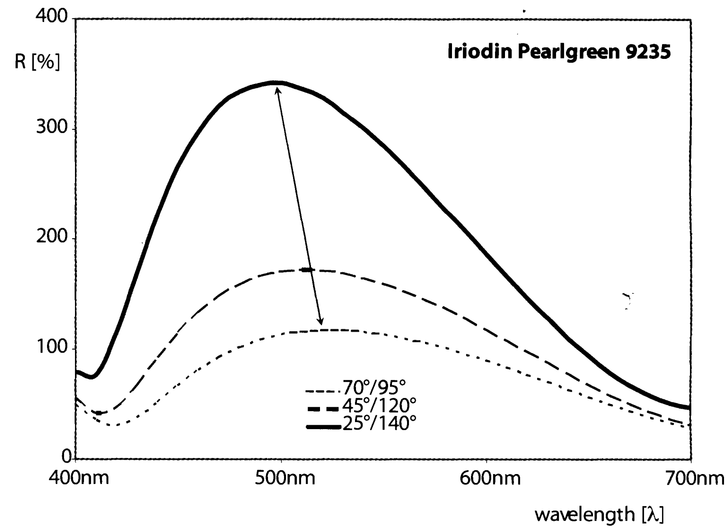
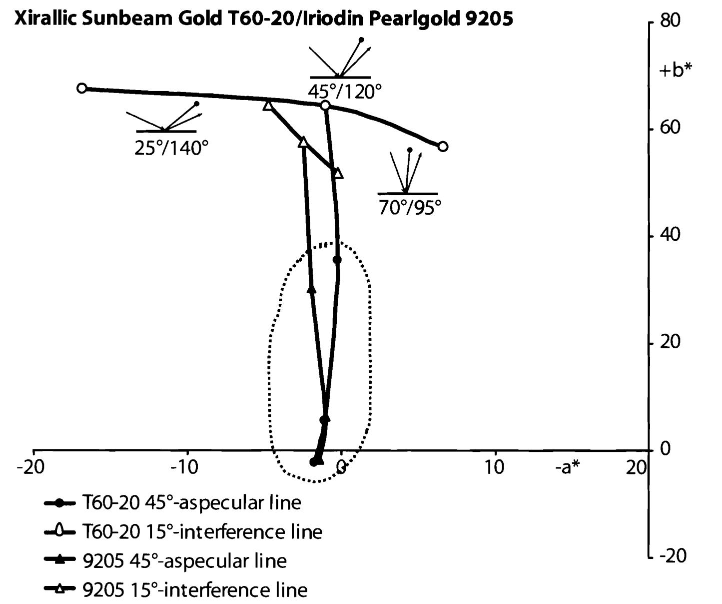


Figure 3 | Under the angular relationships currently employed, two similarly formulated interference pigments, such as Iriodin Pearl Gold and Xirallic Sunbeam Gold, yield virtually identical results. However, interference measurements clearly indicate that the interference color of the Xirallic pigment is strongly shifted toward the green when illuminated at grazing incidence.



inspector's eyes) and the plane of the sample undergoing testing will then have changed. For the case in question, the difference angle will become -10°, i.e., viewing will be from a *trans*-location. Viewing will then take place from the far side of the specularly reflected beam, referred to the incident (*trans*-side) illumination.

Continuing to tilt the test panel downward in 5° increments will increase the angle of incidence from 80° to 85° and 90°. The angle of specular reflection will then change from 100° to 95° and 90°, respectively; the viewing angle will change from 110° to 115° and 120°, respectively, and their difference will change from -10° to -20° and -30°, respectively (Figure 4).

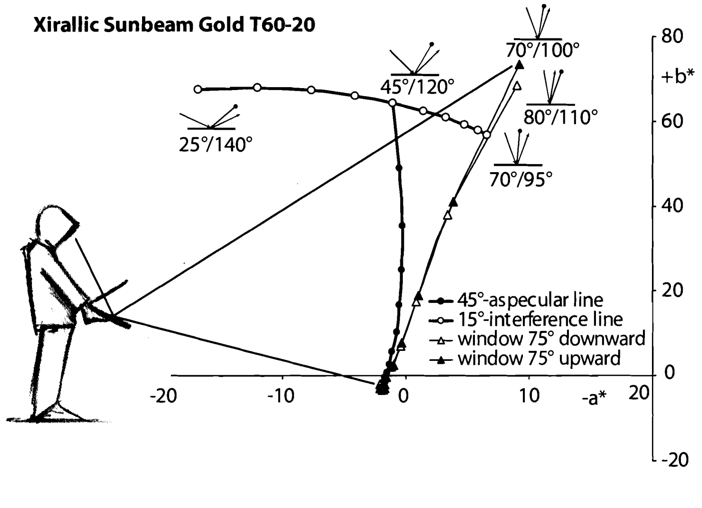
The next 5° increment will shift the angle of illumination to the other side of the normal to the panel's surface, i.e., increase it to 95°. The angle of specular reflection will then be 85°, while the viewing angle will increase to 125°. The difference between the latter two angles will have meanwhile become 40°, and viewing will have shifted to a *cis*-location. Viewing will then be from the same side of the normal to the panel's surface as the incident (*cis*-side) illumination. Viewing will continue to be from the *cis*-side for further increments in the angle of illumination. Shifts from the *trans*-side to the *cis*-side, and *vice versa*, will yield differing measurement results for the same absolute values of the difference in the angle of specular reflection and the viewing angle. This is why such measurement results should not be compared.

Similar relationships occur when the test panel is tilted upward, i.e., in this case, the angles of illumination, viewing and the difference between the angle of specular reflection and the viewing angle will simultaneously vary (Figure 5). These geometries, which occur when visually characterizing samples while standing opposite a laboratory window, never occur in the case of commercially available photometric instrumentation, which is why agreement between visual and instrumental characterizations of interference pigments will never occur.

Figure 4 | The starting point for viewing opposite a window is a location of the test panel, for which the viewer will see the window reflected in the coat of paint. The table assumes an angle of illumination of 75°. The viewer tilts the test panel upward, toward their head (the first seven rows of the table) and downward, away from their head (the final six rows of the table). In the first case, the viewer changes the location (trans side – cis side) of the light source relative to the viewing location.

illumination [°]	specular [°]	viewing [°]	aspecular [°]	side
105	75	135	60	cis
100	80	130	50	cis
95	85	125	40	cis
90	90	120	-30	trans
85	95	115	-20	trans
80	100	110	-10	trans
75	105	105	0	cis/trans
75	105	105	0	cis/trans
70	110	100	10	cis
65	115	95	20	cis
60	120	90	30	cis
55	125	85	40	cis
50	130	80	50	cis

Figure 5 | As usual, the viewer examines the test panel opposite a window and tilts the panel upward and downward. Those motions yield colors that fail to reproduce the interference shift (interference line). There is also no correlation to the results (aspecular-reflectance line) of conventional measurements. The initial situation involved illumination at 75°.



Light Booth

There are two methods for characterizing test panels in a light booth. Either the test panel involved is tilted in one direction or the other, without establishing the angular relationships to be involved, as in the case of visual characterizations, or the test panel is placed on a mechanism situated in the illumination chamber that predetermines certain angular relationships. Illumination is vertically from above in either case. Such mechanisms usually presume an angular relationship for which the viewer will see the light source reflected in the test panel, but take no account of the viewer's height and distance from the test panel, i.e., take no account of the viewing location.

Assuming that the test panel is inclined at an angle of 20° with respect to the laboratory table, we arrive at the following angular relationships, referred to the plane of the test panel. The angle of illumination will be 70°, and the viewer will see the light source reflected in the panel when viewing it at an angle of 110°. The test panel is then tilted upward and downward through 10°, yielding the following angular relationships. The angle of illumination will change from 70° to 80°, and the angle of specular reflection will become 100°. Viewing will then be at a *trans* difference between the angle of specular reflection and the viewing angle of -20°. Similarly, tilting the test panel in the other direction through 10° will yield a *cis* difference angle of +20°. The viewing angle will change from 70° to 60°, the angle of specular reflection will become 120° and the viewing angle will become 100°. No such angular relationships are implemented in any items of photometric instrumentation.

In the case of "uncontrolled" motions of a test panel, it is presumed that the incident light beam is perpendicular to the plane of the panel. Viewing will then be at an angle of, for example, 135°, depending upon the viewer's height, their distance from the test panel, and the location of their eyes. If the test panel is then tilted through 5° toward the viewer, the angle of illumination will change from 90° to 85°, the angle of specular reflection will change from 90° to 95° and the viewing angle will change from 135° to 140°, yielding a *cis* aspecular angle of 40°. Continuing to tilt the test panel toward the viewer will increase all of the angles involved (Figure 6).

If the test panel is tilted in the opposite direction, i.e., away from the viewer, both the angle of illumination and the viewing angle will decrease and the angle of specular reflection will be correspondingly increased. The included angle between the specular reflection and the viewing angle will initially be at a *trans* location and transit to a *cis* location when the angle of illumination changes from 70° to 65°. As in the cases of the angular relationships for "controlled" viewing in a light booth and those for viewing opposite a window, the angular relationships that apply here have not been implemented in any commercially available photometric instrumentation (Figure 7), which is why no comparisons of visual and instrumental characterization of interference pigments can be made. That fact frequently leads to wrong decisions when assessing colors and differences in colors.

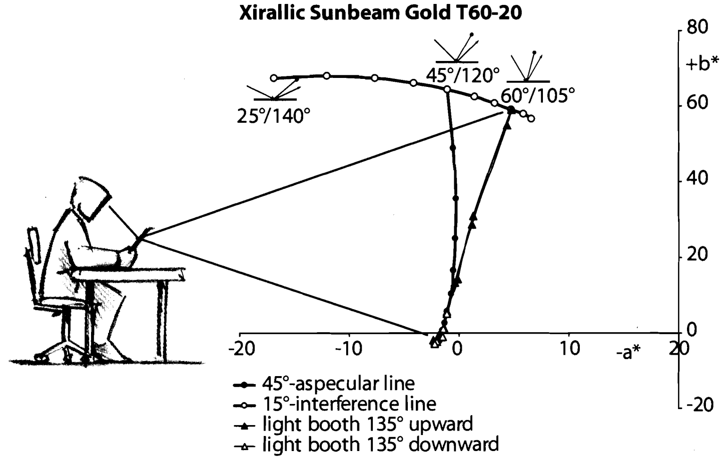
However, there is a method for visually characterizing interference pigments and admixtures pigmented with interference pigments that overlaps instrumental characterizations. The optical properties of interference pigments may be acquired if the angle of illumination is varied while the aspecular angle, i.e., the difference between the angle of specular reflection and the viewing angle, is held constant. When illumination and reflection are at steep angles, measurements are made at angles close to the angle of specular reflection.

In the case of flat angles, measurements are also made at angles close to the angle of specular reflection. Visual characterization involves laying a test panel flat on the palm of one's hand and extending the arm involved toward a light source such that grazing incidence results. One then alters the test panel's location by translating it downward, while keeping it parallel to its original orientation, keeping

Figure 6 | In the light booth, the viewer takes a stance in which he holds the test panel in a horizontal orientation. Light from the light source illuminates it at an angle of incidence of 90°. Although the viewer does not alter their absolute location, the viewing angle will increase or decrease relative to the plane of the panel when they tilt the panel. The first five rows of the table list the angular relationships that occur when the panel is tilted downward. The final eight rows of the table list the angular relationships that occur when the panel is tilted upward.

illumination [°]	specular [°]	viewing [°]	aspecular [°]	side
110	70	155	85	cis
105	75	150	75	cis
100	80	145	65	cis
95	85	140	55	cis
90	90	135	±45	cis/trans
90	90	135	±45	cis/trans
85	95	130	-35	trans
80	100	125	-25	trans
75	105	120	-15	trans
70	110	115	-5	trans
65	115	110	5	cis
60	120	105	15	cis
55	125	100	25	cis

Figure 7 | Even in the light booth, the viewer fails to perceive either the interference colors or the effect colors that result from measurements conducted at various differences between the angle of specular reflection and the viewing angle, for the same angle of illumination. The conditions under which measurements were conducted in the light booth were illumination at an angle of incident of 90° and a viewing angle of 135°.



the arm involved outstretched and simultaneously walking toward the light source in order to allow the light source to illuminate the test panel at steeper angles of incidence. The important factor here is the parallel translation of the test panel necessary in order to maintain a constant difference between the angle of specular reflection and the viewing angle (Figure 8). The colors observed will then agree with instrumental characterizations.

Figure 8 | Ideal characterizations of interference pigments are the result of illumination at various angles of incidence for a constant difference angle. For a visual characterization, the viewer translates the test panel upward and downward, while maintaining it parallel to its original orientation and views it at angles close to the angle of specular reflection.

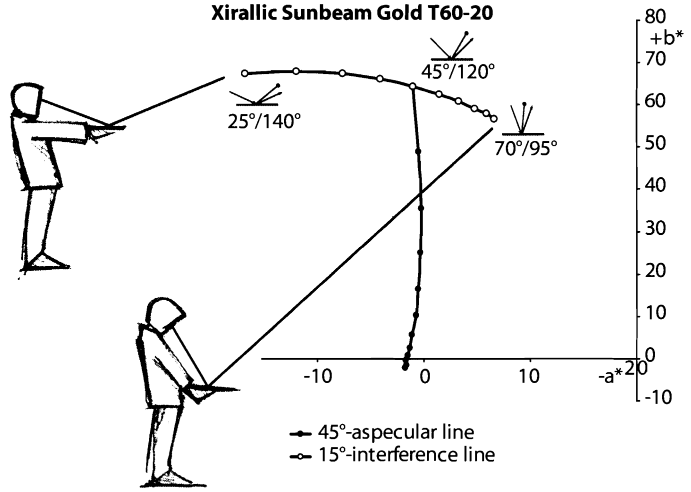


Figure 9 | The experimental conditions involve viewing a vehicle's hood while standing alongside the vehicle. The viewing distance is chosen such that the sun, which is on the opposite side of the vehicle and at an altitude of 60°, is reflected in the hood. This annual extreme occurs in Münster, Germany, which is situated at 52° north latitude, at noontime in mid June. While measurements are in progress, the solar altitude in Fort Lauderdale, Fla., will be increasing, and will reach more than 85° at noon, local time.

Solar attitude [°]	specular [°]	viewing [°]	difference [°]
85	95	120	-25
80	100	120	-20
75	105	120	-15
70	110	120	-10
65	115	120	-5
60	120	120	0
55	125	120	5
50	130	120	10
45	135	120	15
40	140	120	20
35	145	120	25
30	150	120	30
25	155	120	35

← Fort Lauderdale →
← Münster →

Interference pigments, such as Iriodin Pearl Gold and the similarly formulated Xirallic Sunbeam Gold, may also be distinguished using this visual method. However, conventional visual and instrumental methods yield hardly any differences between those pigments.

The Effects of Solar Altitude

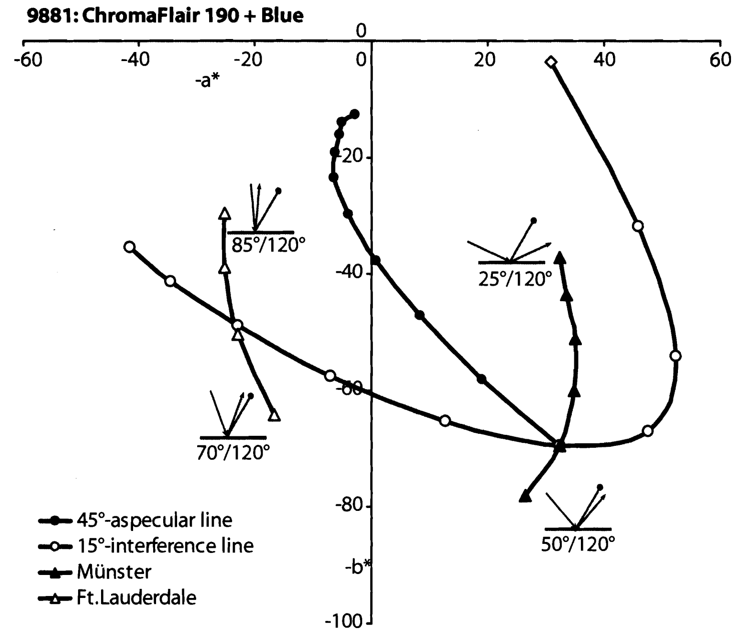
When assessing interference colors *in vivo* on a vehicle, some of the factors that must be taken into account are the current solar altitude, the viewer's height and the viewer's distance from the vehicle. In conjunction with the solar altitude, yet another factor that plays a role is the geographic latitude of the viewing site involved. If we ignore spectral and intensity shifts due to the Rayleigh and Tyndall effects and assume uniformly white sunlight, we arrive at two types of examples having differing sets of parameters.

Münster, Germany, which is situated at 52° north latitude, has a lot of rain and few sunny days. Fort Lauderdale, Florida is situated at 26° north latitude, has little rain and many sunny days. It is assumed that the viewer is situated at the same location opposite the vehicle's left-front wheel and looking at its hood. The sun is shining on the opposite side of the vehicle such that sunlight is reflected off its hood, toward the viewer. At noon in Münster in mid June, the solar altitude (90°, minus Münster's latitude, plus the solar declination) will be its annual maximum of 61°. The viewer will perceive the resultant interference color occurring close to the specular reflection (Figure 9). Although a viewer situated at the same location with respect to the same vehicle in Fort Lauderdale, where it will be earlier in the morning, will perceive the same color as the viewer in Münster, it will have changed when noon rolls around, since the solar altitude will have increased to 81°. The interference colors occurring between those two solar altitudes cannot be observed in Münster, since the solar altitude there never exceeds 61° (Figure 10).

Although this example should not be construed as an appeal for new methods and alternative conditions for characterizing the colors of interference pigments, it indicates how drastic the effects of angle of illumination on resultant interference colors can be. In any event, the proposed method for visually and instrumentally characterizing interference pigments using various angles of illumination is suitable for assessing even extreme *in vivo* experiences.

Interference pigments have optical properties that may be acquired using new visual and instrumental methods. Conventional methods provide little information that will allow formulating descriptions of value for incoming-goods inspections and quality con-

Figure 10 | The effects of solar altitude will be clear from this admixture of ChromaFlair 190 pigment and an absorbing blue pigment. Although a viewer in Münster, Germany, will perceive, at most, colors from the violet spectral range, a viewer in Fort Lauderdale, FL, will also perceive green colors. In both cases, the experimental conditions involve a solar altitude of 60° and a viewing distance, for which the sun, which is on the other side of the vehicle involved, is reflected in the vehicle's hood, i.e., illumination at an angle of incidence of 60° and an angle of specular reflection of 120°. Since the solar altitude can increase beyond that in Fort Lauderdale, other interference colors will also be perceived there.



trol. Conventional methods are also hardly suitable for identification and characterization purposes, which means that expending more time and effort on their identification and characterization and obtaining incorrect results are inevitable. Further work on the optical properties of interference pigments will only benefit all involved.

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Notes

The various conventions for designating angles in the case of reflectance measurements were discussed by ASTM Working Group E 12.06. In contrast to the standard practice, which associates the normals to surfaces with 0°, the convention employed here superimposes a graduated, semicircular arc covering the angular range 0° – 180° whose plane is normal to the surface whose reflectance is to be measured on that surface, which means that the normal to the surface will be at 90°, rather than 0°. Although that approach yields clearer descriptions of the angular relationships involved in reflectance measurements, it causes purists' hair to stand on end. For more information, e-mail wcramer@muenster.de.