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An Instrumental Study of the Optical Characteristics of Nacreous and Interference Pigments

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Synopsis—NACREOUS or PEARLESCENT PIGMENTS are used to impart pearl luster to many items, including cosmetics. The pigment particles are transparent platelets of high refractive index. Although the most significant property of a nacreous pigment is high specular reflectance, the specific OPTICAL BEHAVIOR of a given pigment is determined by the relative magnitudes of specular reflection, diffuse reflection, and transmission. These factors can be compared by measuring reflectance at various angles of illumination and angles of viewing.

INTERFERENCE PIGMENTS are nacreous pigments in which the platelet thickness is such that COLOR is produced by light interference phenomena. Interference color is dependent on angle of incidence. Furthermore, interference pigments display two colors, a reflection color and the complementary transmission color. These characteristics have been studied by means of the Leres Trilac GONIOSPECTROPHOTOMETER. The measurements make possible the characterization of nacreous and interference pigments, and their comparison in terms of quality.

INTRODUCTION

Nacreous or pearlescent pigments have long been used in cosmetics, the first large-scale example being natural pearl essence in pearly nail enamels. With the increased variety of nacreous pigments which have become available, they are now widely used in lipsticks, eye makeup,

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face powder, and liquid makeup. The newer nacreous pigments create iridescent and gold as well as frosted effects (1).

Nacreous pigments have traditionally been evaluated by visual techniques. The first nacreous pigment was natural pearl essence in which the pigment particles are guanine-hypoxanthine platelets, and its original use was in the preparation of simulated pearls. The initial test for pearl luster, therefore, consisted in visual comparison of simulated pearls which were prepared simultaneously from the test sample and from standard pearl essence samples. The technique is capable of discerning very small differences between samples and is still in use, especially in the evaluation of the more brilliant nacreous pigments, such as natural pearl essence plates.

A drawdown method is very effective with the less brilliant nacreous pigments, such as the bismuth oxychloride and titanium dioxide–coated mica pigments which have had extensive applications in cosmetics during recent years. The sample for test is dispersed in a suitable vehicle, such as nitrocellulose lacquer. Using a film applicator, the dispersion of the test sample and a dispersion of a standard are made into adjacent films on a half-black, half-white card.

The TiO_2–coated micas include nacreous pigments which are also interference pigments, producing color by means of thin film interference phenomena (2, 3). In the case of TiO_2–coated mica, a TiO_2 layer on each broad face of the mica platelets is of such thickness that a specific color is reflected and its complement is transmitted. Drawdowns very effectively show small differences in color as well as in nacreous luster, but the advent of color in nacreous pigments made an instrumental method of measurement even more urgent than was the case with the white pearlescent pigments.

Nacreous luster is a directional effect. The pigment particles are transparent platelets of high refractive index which behave like small mirrors. They are oriented parallel to one another in multiple planes (Fig. 1). Because the reflections arise from many layers of platelets, the eye receives an impression of shimmer or pearly luster as opposed to the sharp, metallic reflection characteristic of a single reflecting surface. The higher the luster of a specific nacreous pigment, the greater is the specular or mirror-like reflection, *S,* in Fig. 1. The lower the luster, the greater the diffuse reflection, *D,* which consists of light scattered in nonspecular directions. Finally, a portion of the light, *T,* is transmitted through the nacreous pigment film. The visual effect of a nacreous pig-

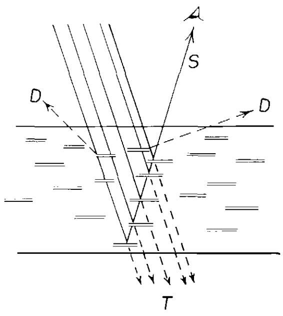

Figure 1. Reflection of light by nacreous pigment platelets in film. *S,* specular reflection; *T,* transmission; *D,* diffuse reflectance

ment is determined by the relative magnitudes of specular reflectance, diffuse reflectance, and transmittance, and by the color characteristics of each. Color, which is very subtle in the "white" nacreous pigments, is the chief property of the interference pigments.

S and *D* can be measured with a goniophotometer, an instrument in which reflectance is measured as a function of angles of illumination and viewing. Hunter (4) has demonstrated the utility of the goniophotometer in the measurement of gloss. Color is, of course, measured by a spectrophotometer. An instrument which would be useful for measuring both the directional character of nacreous reflection and the color of interference pigments is a combination goniophotometer and spectrophotometer. No commercial instrument is at present completely versatile as both a goniophotometer and a spectrophotometer; Hemmendinger and Johnston (5) and Billmeyer and Davidson (6) have adopted the term "goniospectrophotometer" to describe a spectrophotometer with goniophotometric capacity being secondary. (The reverse case is an instrument called a "spectrogoniophotometer.") A commercially available instrument combining spectrophotometric and goniophotometric capability is the Leres Trilac spectrophotometer,* a recording goniospectrophotometer which was used in the present work. This instrument is particularly suitable because it obtains spectrophotometer curves at specular reflection as well as at other angles. The measurements reveal many of the characteristic properties of nacreous and interference pigments.

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* Kollmorgen Color Systems, Tatamy, Pa. 18085.

EXPERIMENTAL

The nacreous pigment is dispersed in nitrocellulose drawdown lacquer which has the following composition:

Nitrocellulose, RS type, 15–20 sec	2.9%
Nitrocellulose, RS type, 30–40 sec	6.6
Isopropanol	5.1
Amyl acetate	44.8
n-Butyl acetate	37.6
Monobutoxydiethylene glycol	3.0
	100.0%

In this particular formulation, which has a viscosity of approximately 2000 cP at 25°C, the two grades of nitrocellulose* are used in order to obtain the desired combination of solids content and viscosity. The monobutoxydiethylene glycol is used to prevent "blushing" or clouding of the lacquer film by condensation of water vapor from the atmosphere. Other vehicles can be devised for nacreous pigment preparations incompatible with nitrocellulose.

Drawdowns of the nacreous pigment dispersion are made on a card which has both a black and a white area. A pool of the drawdown suspension is poured on the card held firm against a Bird vacuum plate, and is drawn into a film by means of a Bird film applicator producing a wet film of approximately 0.003 inch thickness.†

The sample for the Trilac spectrophotometer is a 7.5 × 7.5 cm square cut from the black portion of the card. For special purposes, a sample may be taken from the white portion of the card, as will be mentioned below. This square is placed in the sample holder of the Trilac with a specific orientation, i.e., with the drawdown direction perpendicular to the plane of the light beam. The use of a constant orientation is an important factor with pigments which have platelets longer than they are wide.

The Trilac instrument may be used to measure either reflected or transmitted light, although the present work is confined to reflectance measurements. (Transmission characteristics are inferred from certain

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* Hercules, Inc., Wilmington, Del. 19899.

† The card used in these experiments is Opacity Chart Form 5C of the Leneta Company, Ho-Ho-Kus, N. J. 07423. The Bird items are available from Gardner Laboratory, Inc., Bethesda, Md. 20014. The vacuum plate is Catalog No. AG-3876 and the film applicator is Catalog No. AG-3800-L.

reflectance curves.) The light from a tungsten source first passes through the monochromator before it is allowed to fall alternately on the sample and a reference standard which are located adjacent to one another and in the same plane (5, 6). Two adjustments are made to set the angle of incidence and the angle of viewing. Restrictions on the settings are that the total angle between the incident beam and the viewed beam cannot be less than 30° nor more than 90°. Thus, the values of the angles i/v, i.e., angles of incidence and viewing, respectively, must be between —15°/15° and —45°/45° for specular reflectance. Diffuse reflectance, however, can be measured over a greater range of angles, e.g., up to —15°/75°. In either case, the reflectance is recorded as a function of wavelength from 400 to 700 nm.

The reference standard for these experiments was a barium sulfate pressed cake which was chosen as a white diffuse reflector. Because the reflectance at specular angles from nacreous surfaces would be considerably greater than specular reflectance from the $BaSO_4$ standard, a neutral density filter transmitting 10% of the light was placed between the nacreous sample and the light detector for angles close to specular. This filter reduced the intensity of the reflected light sufficiently to obtain a balance against the $BaSO_4$ cake without distorting the color characteristics of the reflected light. For readings far from specular, e.g., —15°/45° to —15°/75°, where diffuse reflectance by nacreous samples is much less than by $BaSO_4$, the filter was either removed or placed in front of the $BaSO_4$. Reflectance readings made with the filter were multiplied or divided by 10 to make all readings comparable. The reflectance readings are relative to the reflectance of the $BaSO_4$ standard under the same angular conditions, and do not indicate the absolute reflectance of the nacreous pigment sample.

Some of the nacreous pigments on which data are reported are not at present commercially available.

RESULTS AND DISCUSSION

Nacreous Luster

The essentially specular nature of nacreous luster has been mentioned. A first impression of the reflectance of nacreous pigments can be obtained by examining specular reflectance with the Trilac goniospectrophotometer. Figure 2 demonstrates the reflectance of natural pearl essence plates (crystals approximately $30 \times 6 \times 0.07$ μ from fish scales) and natural pearl essence "needles" (a mixture of plates and the

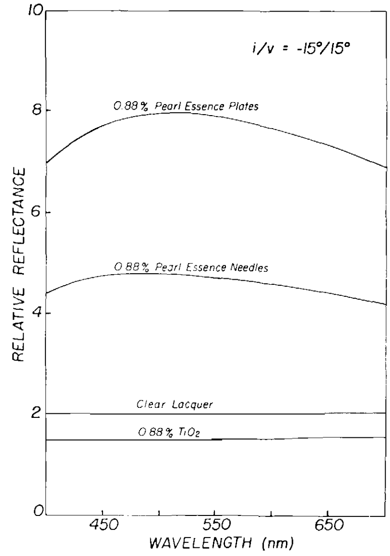

Figure 2. Spectrophotometric curves at specular reflection of pearl essence plates and needles

very narrow platelets, approximately 30 × 1 × 0.07 μ, from fish skin). Detailed descriptions of pearl essence and other nacreous pigments are given elsewhere (1, 3). Both curves are based on drawdowns of 0.88% pearl essence crystals. (All concentration figures refer to weight per cent in the wet drawdown lacquer.) A curve for the reflectance of a clear lacquer film is shown as a blank. Finally, to illustrate the difference between a nacreous and a nonnacreous pigment, a curve is shown for a conventional TiO_2 dispersion, also at 0.88% pigment in the lacquer.

Figure 2 was made at —15°/15°, that is, —15° is the angle of incidence and +15° is the angle of viewing. The known higher luster of pearl essence plates in comparison with needles is shown by the higher specular reflectance of the plates. The fact that all the curves are so close to the horizontal indicates that the colors are essentially "white." Nevertheless, the plate pearl essence coating appears very slightly greenish yellow at specular reflection in comparison with the TiO_2, as is evident in the peak of the spectrophotometric curve for plates at approximately 520 nm. This very weak color arises from the fact that pearl essence plates are interference films. The optical thickness of the plates, or the geometrical thickness multiplied by the refractive index (1.85), is close to one-quarter of 520 nm, causing the plates to have maximum reflectivity at this wavelength.

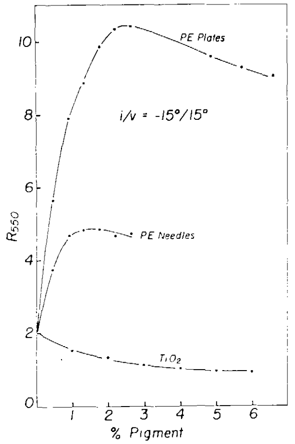

Figure 3. Dependence of relative reflectance at 550 nm (R_{550}) on pigment concentration

As for the TiO_2 curve, it falls below the lacquer blank. In other words, the gloss of the lacquer is diminished by the presence of TiO_2 which causes light to be scattered in all directions.

The nacreous effect is of course dependent on the concentration of nacreous pigment. Concentration series were run on pearl essence plates, needles, and TiO_2. The reflectance at 550 nm is plotted against concentration in Fig. 3. (The center of the visible range was arbitrarily chosen for comparison of these "white" products.) Reflectance of plates increases up to a concentration of 2.6% crystals and then falls off. A point is reached where increased concentration does not improve specular reflectance for at least two reasons: with increased concentration the smoothness of the surface of the lacquer film is impaired, decreasing gloss; with increased concentration the crystal platelets are more likely to interfere with each other's orientation. The concentration at which these effects occur depends on the particular lacquer being used as a vehicle, since it is a function of concentration in the dry film.

The curve for pearl essence plates reaches a maximum relative reflectance, R_{550}, of 10.4. In contrast, the pearl essence needles peak at 4.8. In the case of the nonnacreous TiO_2, specular reflectance decreases with increasing pigment concentration, demonstrating a fundamental difference between nacreous and conventional pigments. Figure 3 also shows that a nacreous pigment of inherently lower luster cannot be used at a higher concentration to duplicate the effects of a pigment of higher luster. A limiting luster is obtained under given conditions of use.

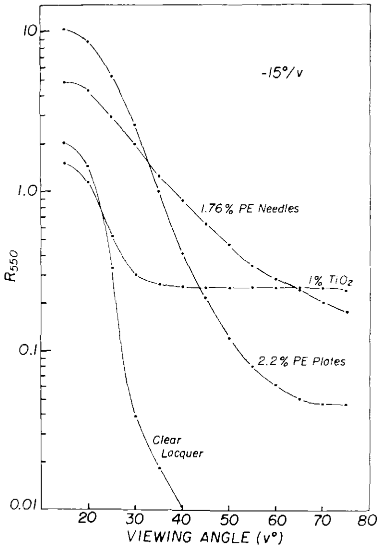

Figure 4. Directional reflectance of pearl essence. Angle of incidence, —15°

It has been stated that nacreous reflection is directional in character. Figure 4 presents goniophotometric plots for pearl essence plate and pearl essence needle samples which were at or close to optimum concentrations for specular reflection. Reflection was viewed at varying angles with the angle of incidence kept constant at —15°. The clear film and TiO_2 samples are once again added for comparison. The first point on each curve is at the viewing angle of 15° and represents specular reflectance. Diffuse reflectance is measured at all other angles. Each curve is at its maximum at specular reflection.

The pearl essence plate sample has the highest specular reflectance, and reflectance falls off rapidly as the viewing angle increases. The less lustrous needle-type pearl essence, on the other hand, has lower specular reflectance than the plate-type and higher diffuse reflectance. Thus, the two curves cross.

What is the reason for these relationships? Diffuse reflectance in pearl essence arises mainly from scattering of light by the crystal edges. The total edge effect is very much greater for the narrow needles than for the wider plates. As a consequence, the needles have higher diffuse reflectance and lower specular reflectance, since the scattered light is not available for specular reflection.

The curve in Fig. 4 which falls most rapidly is that of the clear lacquer, an example of a glossy surface with very little diffuseness. The

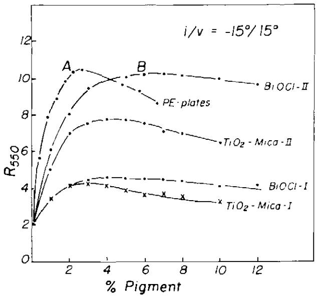

Figure 5. Relative reflectance at specular reflection of several nacreous pigments

TiO_2 film, in contrast, is a rather diffuse reflector. Specular reflectance is lower than that of the clear lacquer film, and diffuse reflectance is relatively high and essentially constant over the range of viewing angles which can be covered by the instrument.

The slopes of the curves are quite gentle between the viewing angles of 15° and 20°. A glossy surface is expected to give a sharply spiking curve, as was demonstrated by Hunter (4) and Billmeyer and Davidson (6). The broadness of the maxima obtained with the Trilac spectrophotometer is attributable to the rather wide viewing beam, which subtends a total angle of 19°. This characteristic limits the resolution of the Trilac spectrophotometer but, on the other hand, makes it possible to measure specular reflectance with a fair degree of reproducibility, which would be very difficult at the peak of a spiking curve. The average deviation from the mean of repeated readings is less than 0.1 relative reflectance unit in the 5.0 to 10.0 range.

Several other "white"-reflecting nacreous pigments were compared with pearl essence plates for specular reflectance. These were two samples of bismuth oxychloride and two of titanium dioxide–coated mica. In each case the sample of lower quality is designated as I, the higher as II. The reflectance at 550 nm is plotted against concentration in Fig. 5. BiOCl-I and TiO_2-mica-I do not approach the specular reflectance of pearl essence plates no matter what concentration is used. TiO_2-mica-II comes closer, and BiOCl-II reaches almost the same specular reflectance as pearl essence plates, although at a higher concentration. However, because BiOCl has a much higher specific gravity (7.7) than pearl essence crystals (1.6), its *volume* concentration at equal specular reflectance is *lower* than that of pearl essence. Thus, BiOCl-II is more reflective than pearl essence plates, no doubt because of its higher refractive index (2.15 and 1.85, respectively). The interesting relationships between volume concentration in the film, refractive index, and specular reflectance will be considered at another time.

Do two nacreous pigment coatings which have the same specular reflectance have the same appearance? One such pair is made up of the plate pearl essence coating marked *A* in Fig. 5 and the BiOCl-II coating marked *B*. In the standard dipping test the two products are *not* identical in appearance: the pearl essence has decidedly better pearl luster than BiOCl-II. Drawn down adjacent to one another on the same card and examined by specular reflection, BiOCl-II looks very slightly pink relative to the pearl essence, which appears slightly greenish yellow. Viewed by nonspecular reflection on the black card, BiOCl-II definitely scatters more light than the pearl essence and is thus more opaque. Finally, BiOCl-II is also more opaque at specular reflection.

The differences seen on the drawdown card are all discerned by the Trilac, and are revealed by the next three figures. Figure 6 compares spectrophotometric curves at specular reflection for the two samples. The two curves meet close to 550 nm, but BiOCl-II is highest at about 660 nm (red), pearl essence highest at 515 nm (green)—hence the slight color difference which was noted. Figure 7 presents the diffuse reflection of the two pigments from the black part of the card and shows that BiOCl-II reflects more than pearl essence at nonspecular angles. Figure 8 compares nonspecular reflectance at —15°/60° against the white part of the card, which means that the reflection is primarily that of the white card as seen through the nacreous pigment. The reflectance through BiOCl-II is less than that through pearl essence because of the higher opacity of BiOCl-II. In other words, BiOCl transmits less, and its lower transmittance more than overcomes the higher diffuse reflectance at

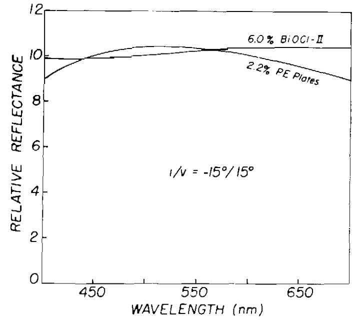

Figure 6. Spectrophotometric curves at specular reflection for plate pearl essence and BiOCl-II

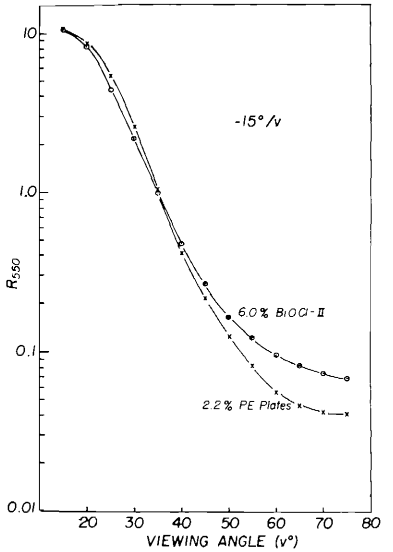

Figure 7. Directional reflectance of plate pearl essence and BiOCl-II

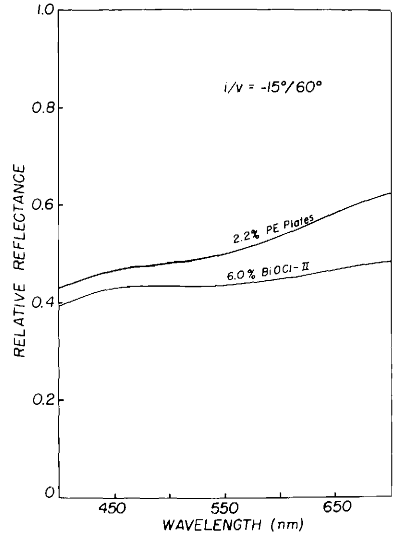

Figure 8. Spectrophotometric curves of white background reflected through plate pearl essence and BiOCl-II

—15°/60° which is evident in Fig. 7. Figures 6, 7, and 8 demonstrate, respectively, *S*, *D*, and *T* of Fig. 1. They indicate why the two pigments which might appear to be equivalent in nacreous luster because of their similar specular reflectance actually look quite different: diffuse reflectance and opacity must be considered as well. The pearl dipping test shows that, of two samples with the same specular reflectance, the greater pearl luster is given by the one with lower diffuse reflectance and lower opacity.

These data demonstrate that two chemically different pigments are very unlikely to give the identical nacreous appearance. The characteristics of the reflection are established by refractive index, platelet dimensions, and the smoothness of the platelet surface. Different chemical substances will generally differ in refractive index, making a perfect match between two different nacreous pigments impossible. Where given chemical components are involved, as in the two pearl essence samples of Fig. 3 and the BiOCl and TiO_2-mica pairs of Fig. 5, differences in nacreous luster depend on platelet dimensions or platelet smoothness or both.

BiOCl-II has a higher refractive index than pearl essence plates, as was noted above. BiOCl-II therefore reflects more of the incident light and conversely transmits less. The crystals (average diameter about 15 μ) are very flat bipyramids rather than perfect platelets, and their average thickness is greater than that of pearl essence plates. Hence, maximum reflectance occurs at a higher wavelength. The optical differences between the two pigments can thus be correlated with the properties of the pigment platelets.

Which is the "best" nacreous pigment? The single criterion most useful for defining the luster of a nacreous pigment is the R_{550}-concentration curve (Fig. 5), but the differences inherent in the various aspects of the pigment as exhibited in Figs. 6, 7, and 8 all contribute to the optical effect. Accordingly, the choice of a nacreous pigment for a particular cosmetic application lies with the cosmetic stylist.

Interference Pigments

The titanium dioxide–coated mica pigments make up a series which include "white"-reflecting platelets ("pearl") and color-reflecting platelets (interference pigments). The mica platelets generally average about 20 μ in length and about 0.3 μ in thickness. The color depends on the optical thickness of the TiO_2 (anatase) layers: pearl, approximately 140 nm; yellow, 210; red or magenta, 265; blue, 330; green, 395. Further increase in TiO_2 thickness produces a second yellow and a repetition of the color cycle. Spectrophotometric curves at specular reflection are given for several colors in Fig. 9. These measurements were made as usual on the black portion of the drawdown card.

The reflection curve for yellow has a minimum in the blue portion of the spectrum. The interference films are of such thickness that blue is eliminated from the reflection. The residual components of the white light, which are reflected, create an impression of the complementary color, or yellow, on the eye. It is seen from the curve that the residual light includes violet, yellow, and red. The combination of this spectrophotometric curve with the pigment's directional reflectance has the visual impact of "gold." The light which is eliminated from the reflection is actually transmitted, as will appear below.

The red curve shows the reflection which remains after green is eliminated by interference. The residual light consists primarily of violet and red.

The curve for blue is the first which has both a minimum and a distinct maximum. The minimum represents the elimination of yellow-orange by interference, the maximum the reinforcement of blue by inter-

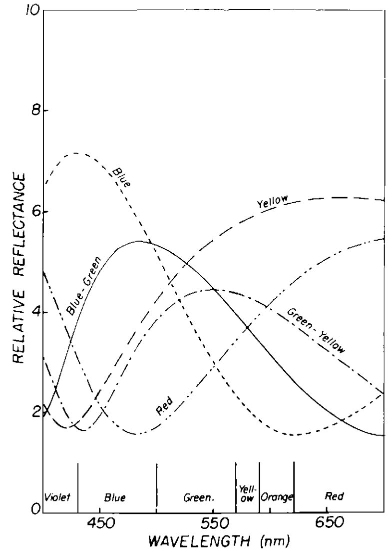

Figure 9. Spectrophotometric curves of TiO_2-mica interference pigments at specular reflection

ference. Because of this two-part interference, the color is more intense than that of the preceding pigments.

The blue-green curve has a maximum but no minimum within the visual range. Manual operation of the Trilac past the recording range of 400–700 nm shows that there are minima at 395 and 712 nm just beyond the visible on either side. This green has relatively low visual color intensity because of the absence of a minimum in the visual region.

These colors are called "first colors" merely to indicate that they are the colors which first appear when films are thickened sufficiently to produce interference. Further increase in thickness of the TiO_2 layer leads into "second colors," beginning with a greenish-yellow. This film thickness produces the green-yellow curve of Fig. 9, which once more has both a minimum and a maximum. The green-yellow appears much more lustrous to the eye than the blue-green, even though its maximum reflectance is smaller. The reason is that the green-yellow curve peaks at 550 nm, where the eye is most sensitive, and in general parallels the visual sensitivity curve.

The curves of Fig. 9 were obtained at —15°/15°, which is the smallest specular angle attainable with the Trilac. A fundamental characteristic of interference colors is that they change with angle of incidence.

If it were possible for specular reflectance to be measured at an angle of incidence of 0°, all the curves of Fig. 9 would be shifted slightly to the right.

Johnston, who has studied the dependence of color on angle of illumination and viewing in metallic paint films (7), has applied the term "goniochromaticity" to this property (5), and this term is very apt for interference colors.

Goniochromaticity is illustrated by curves *A* and *B* of Fig. 10 which is devoted to a blue-reflecting TiO_2-mica. Curve *A* is analogous to those of Fig. 9, i.e., at —15°/15°. Curve *B* is at —45°/45°. The curve for specular reflectance at the higher angle of incidence moves to the left in agreement with interference theory (2, 3), and the reflection color shifts in the direction blue to purple. Note also that curve *B* at the higher angle of incidence is higher than curve *A*, in accordance with Fresnel's formulas for the reflection of light which show that specular reflectance increases with increasing angle of incidence.

Figure 11 demonstrates the two-color effect of an interference pigment. *A* is once again the —15°/15° curve for the blue-reflecting pigment on a black background. *B* is the same pigment at —15°/15° against the white part of the card. The curve is essentially the same

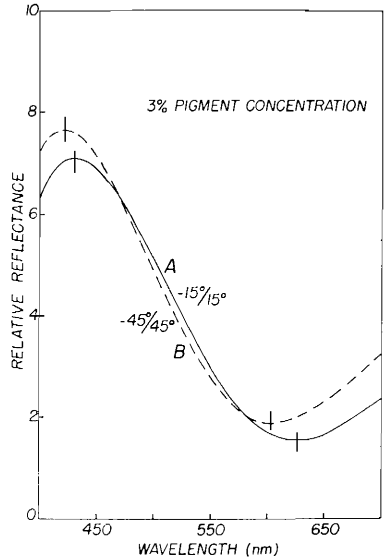

Figure 10. Spectrophotometric curves of blue-reflecting interference pigment at different angles of incidence

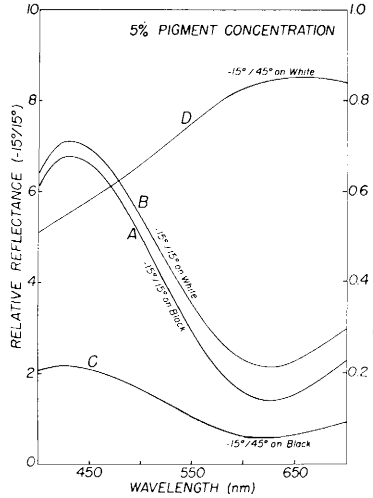

Figure 11. Spectrophotometric curves demonstrating reflection color (*A, B*) and transmission color (*D*) of blue interference pigment

but somewhat higher than that obtained against the black background; however, the increase in reflectance at the minimum is indicative of some small diminution in color intensity. At the specular angle, then, the color is relatively independent of background.

Diffuse reflectance curves *C* (black background) and *D* (white background) at —15°/45° tell a different story. The reflection against black is still blue, although with much lower color intensity than at —15°/15°. The reflection against white is now yellow: highest reflectivity is in the yellow-red region, lowest in blue. The light viewed at a nonspecular angle as in this —15°/45° example is reflected from the white background. It is transmitted through the interference platelets twice: first as the incident beam, then as the reflected beam. The color observed is thus the *transmission* color as opposed to the *reflection* color which is seen at the specular angle. Interference pigments which have no absorption color thus display two colors which are complementary to one another.

The two-color effect of the red interference pigment has been utilized in "iridescent" nail enamel. Coated on the curved fingernail, the pigment displays a red highlight against a greenish background, and thus duplicates some of the optical characteristics of natural mother-of-pearl.

Curves *A* and *B* of Fig. 11 establish the similarity of blue specular reflectance against black and white backgrounds. On casual visual observation, however, the color intensity against white always seems much weaker, mainly because the pigment is not observed at the exact specular angle. It is possible to darken an interference pigment, thereby sacrificing the two-color play, to obtain apparent intensification of the reflection color. For example, a yellow-reflecting TiO_2-mica which also has a yellow absorption color displays no blue transmission but instead has a more readily seen golden reflection. Such pigments are the "brilliant gold" and "dark gold" TiO_2-mica pigments. In Fig. 12, an interference gold which has no absorption color is compared with one which has absorption color, at —15°/15° against black and at —15°/60° against white. The two pigments look very much the same in specular reflection (*A-S* without absorption color, *B-S* with absorption color). However, they differ markedly in diffuse reflection which reveals the transmission color: the pigment without absorption (*A-T*) is blue-purple, the pigment with absorption (*B-T*) is yellow. Only the first displays striking goniochromaticity.

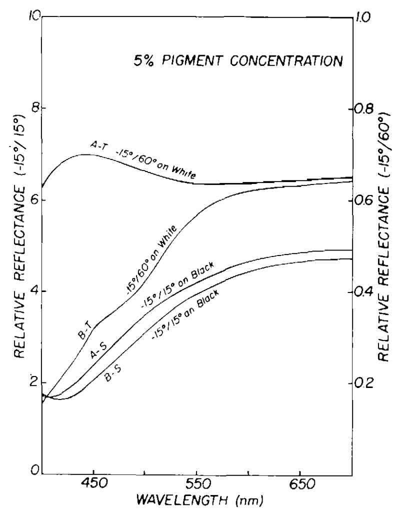

Figure 12. Spectrophotometric curves for gold interference pigments. *A*, without absorption color; *B*, with absorption color; *S*, specular reflection; *T*, transmission

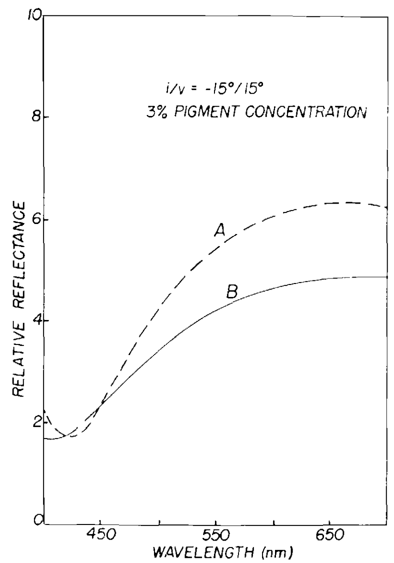

Figure 13. Spectrophotometric curves at specular reflection of two gold interference pigments

The Trilac goniospectrophotometer has served to demonstrate the essential characteristics of interference pigments. The curves can also be used to determine relative quality of pigments of similar color. In Fig. 13, *A* and *B* are, respectively, the yellow-reflecting pigments of Figs. 9 and 12 as compared by specular reflection. *A* has greater color intensity, as seen by the greater sharpness of the minimum and the higher slope. It has a superior luster, as evident from the higher reflectance at the highest part of the curve. It is slightly more orange because its minimum is at a slightly higher wavelength, i.e., displayed in the direction of the red reflecting pigment of Fig. 9. The two pigments could be compared further in diffuse reflectance, in the same manner as for "white" nacreous pigments in the preceding section. The goniospectrophotometric measurements thus may be used for comparing pigments of similar reflection color as well as for exhibiting overall interference pigment charactertistics.

SUMMARY

The optical characteristics of "white"- or "pearl"-reflecting nacreous pigments have been demonstrated in terms of specular reflection, diffuse reflection, and transmission, using a Leres Trilac goniospectrophotometer. Nacreous luster is most nearly described by specular reflectance, but the total visual effect of a particular nacreous pigment depends in addition on diffuse reflectance and transmittance. The appearance of one nacreous pigment cannot be duplicated by a chemically different nacreous pigment since the specific combination of these factors is dependent on the refractive index. The other properties which determine nacreous behavior are platelet dimensions and the smoothness of the platelet surfaces.

Specular reflectance increases with increasing nacreous pigment concentration up to a certain point. Thereafter, further increase in concentration leads to a decrease in specular reflectance. The maximum specular reflectance achievable with a given nacreous pigment is a measure of its inherent nacreous luster.

Interference pigments are examples of nacreous pigments which are color-producing in addition to having the usual nacreous pigment characteristics. These pigments exhibit two kinds of goniochromaticity, or change in color with varying angles of illumination and viewing: (a) the reflection color, which is seen at specular reflection, moves to lower wavelength with increasing angle of incidence, as was shown by spectrophotometric curves at $-15°/15°$ and $-45°/45°$; (b) with the pigment on a white background, measurement at a specular angle exhibits the reflection color, while measurement at a diffuse or nonspecular angle reveals the complement of the reflection color, or transmission color.

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