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A Rapid, Systematic, and Comprehensive Classification System for the Identification and Comparison of Motor Vehicle Paint Samples. I: The Nature and Scope of the Classification System

Numerous forensic science laboratories have approached the identification and comparison of automotive paints differently, but the paint samples are normally subjected to a series of microscopic and chemical examinations that yield chromatic and geometric appearance information as well as fundamental molecular information concerning the types of resins and pigments present.

Fouweather et al [*1*] have adopted the Methuen system [*2*] to standardize the measurement and communication of paint colors among British forensic chemists. Hudson et al [*3*] have attempted to devise a "hue group" classification and indexing system for the classification of commonly encountered paint colors.

Several other nonspecific color coding systems have also been employed. Tippet's study [*4*] of British automotive primers indicated that undercoat and topcoat color combinations in conjunction with X-ray diffraction analysis are useful in identifying the make, model, and year of motor vehicles involved in hit-and-run accidents. Cleverley [*5,6*] also noted that identification of motor vehicle paints and body fillers was possible with microscopic and infrared (IR) techniques. Deaken [*7*] developed a practical approach for the rapid identification of numerous manufacturers and models from 1000 automotive undercoat color combinations. This survey indicated that rapid vehicle identifications were possible when original paint was present.

Information from manufacturers and published literature [*8,9*] indicates that a wide range of topcoat and undercoat chemical paint finishing systems has been and is being employed on motor vehicles. The value of IR techniques in the identification and classification of automotive paints has been demonstrated by Rodgers et al [*10–12*]. Steward [*13,14*], Wheals and Noble [*15*], and Hueske and Clodfelter [*16*] have illustrated that pyrolysis gas chromatographic techniques are capable of identifying, comparing, and classifying automotive topcoat finishes and rubber bumper guards. Analysis of the elemental composition of the pigments present in paints has been studied with laser beam emission spectrography [*17*], energy-dispersive X-ray fluorescence spectrography [*18–20*], and X-ray fluorescence spectrometry [*21*]. The various results obtained indicate that a degree of individuality exists in the elemental profiles and concentrations that may lend itself to both the identification and individualization of paints.

Statistical information as to the number of vehicles of a particular type in a specific geographical location would be of great assistance to the investigator in an identification

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case and to the courts in a comparison case. Tippet's authoritative survey [*22*] on car distributions illustrates what can be achieved with statistically representative motor vehicle distribution data.

Deaken [*7*], Rodgers et al [*10–12*], and Gothard [*23*] attempted to provide information to the courts concerning automotive paint comparisons. Cartwright and Rodgers [*24*] proposed an IR data base for the identification of automotive paints.

For the past several years, an increasing number of different motor vehicle topcoat and undercoat colors, layer sequences, and chemical compositions were being observed within our laboratory. Coupled with these observations were the IR differences being observed in our Regina laboratory and information being obtained from automotive manufacturers concerning new topcoat and undercoat systems. Thus, in the spring of 1975, a pilot project was undertaken to determine if a completely comprehensive microscopic and chemical analysis system for the identification and comparison of motor vehicle paint samples could be developed.

Samples from approximately 1500 automobiles, representing a wide cross section of vehicles, years, and assembly plants, were collected from several body shops and wreckers within the Edmonton area. At the completion of this pilot survey, we were convinced that, providing a statistically representative number of samples from all manufacturers were collected, it would be possible to (1) rapidly identify from paint samples the manufacturer, vehicle line/series, year, assembly plant, partial vehicle identification number (VIN), and registered owner of motor vehicles involved in hit-and-run-accidents, and (2) accumulate a strong statistical data base that could be employed for the identification and comparison of automotive paint samples.

A comprehensive, computerizable classification system for paint systems on cars and trucks was subsequently developed to encompass the data from 10 000 motor vehicle paint samples as well as information from manufacturers and paint vendors. From the interpretation and evaluation of microscopic and chemical data on original topcoats and undercoats, this system rapidly identifies a limited series of vehicle line/series, years, assembly plants, and partial VIN'S for identifying a hit-and-run vehicle. By using on-line access to provincial motor vehicle branch computers, an investigator can be provided with a listing of vehicles that have corresponding characteristics and registered owners in his specific area. This classification system also selects for the investigator and the courts all statistical information necessary for the comparison of paint from motor vehicles involved in accidents. It assists the court and investigators by determining the individuality of a particular paint sample.

Because a large amount of data has been generated from this project, a series of papers will be forthcoming. Part I outlines in detail the nature and scope of the classification system and the various codes and interrelated data that have been developed. Parts II through VIII will encompass the detailed microscopic and chemical data that has been currently correlated for the Chrysler Corporation; Japanese imports; Ford Motor Corporation; General Motors Corporation; American Motors Corporation and North American imports; British and European imports; and, finally, trucks. The series will be concluded with a description of the statistical compilation and computerization of the data.

Data Classification and Retrieval System

To ensure that the number of samples required for a comprehensive collection could be obtained, we enlisted the assistance of the Edmonton Police Department and Alberta Royal Canadian Mounted Police traffic divisions. Ten thousand paint standards encompassing all 1960 to 1977 North American and imported cars and trucks involved in accidents within Alberta over a seven-month period were collected. No discrimination was made in the collection as to the type of vehicle, position of the sample on the vehicle, or whether the vehicle had a repainted or original finish. Provisions were made so that the samples would be taken to the substrate and placed in specifically labeled envelopes. This ensured that all pertinent information concerning the VIN, license number, area sampled, make, model, and year of the individual vehicle accompanied the paint sample. These collected samples provided the statistically representative data base for the types of vehicles involved in accidents in Alberta as well as the types of paint samples recovered from the damaged areas on these vehicles.

Figure 1 represents the overall network involved in the collection, collation, and correlation of all the information obtained in developing this classification system.

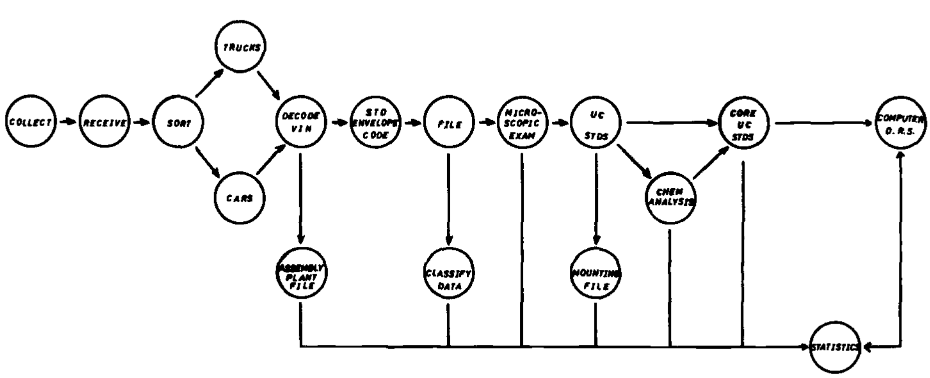
A manual data retrieval system (Fig. 2) was designed for the correlation of the microscopic and chemical information obtained from the paint chip examinations and the manufacturers' information. This system consists of a series of codes designed to readily accommodate the future computerization of all pertinent data necessary for the rapid identification and comparison of paint samples. A detailed explanation of the codes and their relationships follows through the remainder of this paper.

Collection Codes

To systematically collect, file, and correlate the data from the 10 000 samples, extensive series of codes and abbreviations were devised to ensure that each piece of information could be independently and rapidly retrieved.

A manufacturer's code system (Fig. 2) denoted each of the common manufacturers. This six-character coding system consisted of a manufacturer identity code (Table 1) followed by a model year identity code. Thus, a 1973 Chrysler Corporation car and a 1977 White Corporation truck would be listed under manufacturer's codes of 6-73 and 109-77, respectively.

For the individualization of each sample within the paint collection, a sample identification number (SIN) coding system was developed (Fig. 2). This system accommodates the filing and retrieval of the samples and facilitates the systematic incorporation of future samples or factory information. Each paint sample in the collection was assigned a unique ten-character alphanumeric SIN consisting of three distinct parts. The first two characters designate the model year, the next five designate a vehicle line, and the last three designate the sequential sample number. Individual manufacturer's vehicle lines produced since 1960 were identified. Specific vehicle line filing code abbreviations were designed so that each was unique and easily recognized. (These abbreviations will be included within the data of the subsequent papers.) For example, SINs 73SLITE12 and 73SLITE13 identify the twelfth and



VIN = vehicle identification number
STD = standard
UC = undercoat
DRS = data retrieval system

FIG. 1—*General activity network for the project.*

MC[1]	SIN[2]	CD[3]	AP[4]	AOV[5]	UCC[6]	COLOR LAYER SEQUENCE	UCE[7]	CBP[8]
6-68	68FURY 9	*	R	LFF	13	W/Br(U)/W/Gy/Br	68FURY 9	A07
6-68	68MON 7		R	RRF	13	G/Br(U)/G/G*/Gy/Br	68FURY 9	A07
6-74	74SLITE 2	*	A	LFD	12	G*/Gy/Bk	74SLITE 2	C10
6-76	76ASPEN 3		B	H	2	B*/Bk	76VOLAR 4	C15

TC CHEMICAL DATA				UC (1) CHEMICAL DATA				UC (2) CHEMICAL DATA			
RD[9]	MD[10]	PD[11]	CIR[12]	RD	MD	PD	CIR	RD	MD	PD	CIR
R4		1P2		R8		1P7	Gy(6-10)	R8		1P12	Br(6-9)
						1P16				1P15	
						1P19				1P17	
										1P18	
							Gy(6-10)				Br(6-9)
R4	M1	1P18		R8		1P17	Gy(6-16)	R8		1P17	Bk(6-4)
						1P18				1P18	
										1P21	
							Bk(6-9)				

UC (3) CHEMICAL DATA				UC (4) CHEMICAL DATA				UC (5) CHEMICAL DATA			
RD	MD	PD	CIR	RD	MD	PD	CIR	RD	MD	PD	CIR

TC COLOR	ORIG. TC COLOR	TOTAL NO. TC's	TOTAL NO. LAYERS	UC (1) MUNSELL CODE	UC (2) MUNSELL CODE
W	W	2	5	7.5 G 5/2	10 R 3/2
G	G*	3	6		
G*	G*	1	3	N 6.25/	N 2.25/
B*	B*	1	2		

UC (3) MUNSELL CODE	UC (4) MUNSELL CODE	UC (5) MUNSELL CODE

1. Manufacturer's Code, 2. Sample Identity Number, 3. Core Descriptor, 4. Assembly Plant, 5. Area on Vehicle, 6. Undercoat Code, 7. Undercoat Equivalency, 8. Core Board Position, 9. Resin Descriptor, 10. Modifier Descriptor, 11. Pigment Descriptor, 12. Core Infrared.

FIG. 2—*Data retrieval system.*

thirteenth samples in the collection for 1973 Plymouth Satellites. Data concerning commercially available repainting systems can also be accommodated by the SIN. They are designated by abbreviations such as DUPNT, INMNT, and SW for the paint vendors Du Pont, Inmont, and Sherwin Williams, respectively [25].

The assembly plant from which the vehicle originated was designated by the appropriate manufacturer's assembly plant codes (Fig. 2) as used in their VINs. The sampled area on the

TABLE 1—*Manufacturers' identity codes.*

Identity Code	Manufacturer (Cars)	Identity Code	Manufacturer (Cars)	Identity Code	Manufacturer (Trucks)
1	Alfa Romeo	16	Mercedes Benz	101	American Motors
2	American Motors	17	Nisson Motors	102	Chrysler
3	Audi	18	Peugeot	103	Ford
4	Bavarian Motors Works	19	Porsche	104	General Motors
5	British Leyland	20	Renault	105	Hayes
6	Chrysler	21	Rolls-Royce	106	International Harvester
7	Chrysler imports	22	Rover	107	Kenworth
8	Citroen	23	Saab	108	Mack
9	Fiat	24	Subaru Motors	109	White
10	Ford	25	Toyo Kogyo	110	miscellaneous
11	Ford imports	26	Toyota		
12	General Motors	27	Volkswagen		
13	General Motors imports	28	Volvo		
14	Honda	29	miscellaneous		
15	Lancia				

vehicle was identified with a four-character code. Code letters L, R, F, H, T, D, EX, and HB designated the areas left, right or rear, fender or front, hood, trunk, door, extension, and header bar, respectively. By stringing the appropriate code letters together the sampled area can be properly identified (for example, RRF represents the right rear fender and LFHB represents the left front header bar).

Decoding and Filing

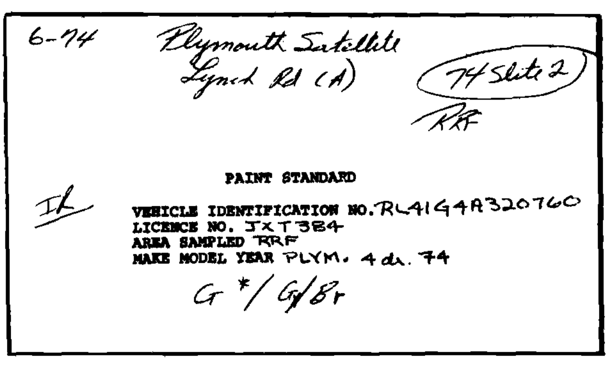
By coordination with the collecting agencies, the "street" samples in this study were received at our laboratory weekly. The envelopes were initially sorted as to cars and trucks (Fig. 1) and subsequently further classified into a manual filing and retrieval system by using only the information placed on the center of the collection envelope by the investigating officer (Fig. 3).

The VINs on the collected envelopes were decoded to ensure the correct vehicle line, series, model year, and assembly plant data were obtained. Vehicle identification manuals dating back to 1960 and information received from the automotive manufacturers and new vehicle sales outlets were used. The VIN manuals were those of the National Auto Theft Bureau and the "Black Books" of National Auto Research Canada.

The various filing codes (manufacturer's, SIN, assembly plant, and sampled area) were placed on the decoded envelopes (Fig. 3) and recorded in the appropriate master files for future correlation and statistical purposes. The envelopes were finally filed according to their appropriate SIN (Fig. 1) by using the hierarchy of manufacturer, division, vehicle line, model year, and finally the sequential number portion of the SIN. This facilitated the very rapid retrieval of any individual segment or sample from the 11 500 samples on file without the rest of the samples being unnecessarily disturbed.

Master Filing System

A master filing system was required to systematically relate the data from each individual sample to the information obtained from the VIN. All specific vehicle lines and individual series that had been produced since 1960 in the assembly plants for each automobile manufacturer were determined from the VIN manuals, manufacturers' information, and trade magazines, such as *Automotive News*. A flow diagram was used to correlate this information so that a series of master chip boards for the specific divisions of each manufacturer could facilitate recording all the source and microscopic information obtained from the collected samples.


6-74 Plymouth Satellite
Lynch Rd (A)
74 Slite 2
RRF

PAINT STANDARD

VEHICLE IDENTIFICATION NO. RL41G4R320760
LICENCE NO. JXT384
AREA SAMPLED RRF
MAKE MODEL YEAR PLYM. 4 dr. 74

FIG. 3—*Collection envelope.*

Figure 4 illustrates the design of two of the Chrysler Corporation Plymouth Divisions boards. To accommodate a large amount of information, each board was designed to represent a specific set of vehicle lines/series for a ten-year period (either 1960 to 1969 or 1970 to 1979). Onto the white side of a Kodak neutral test card (Eastman Kodak Co., catalogue No. 1527795) was drafted the information concerning the model years, vehicle line/series, the series number of the board, and the designation of the color of the undercoat layer next to the surface substrate. To illustrate the vehicle line (Valiant) designations, Columns 1, 4, 5, and 7 represent the specific vehicle series of Valiants, Valiant Broughams, Valiant Dusters, and Valiant Duster 360s, respectively. The black circles within an individual square indicate that the specific vehicle series was not produced in that particular model year. The master chip boards were designed to accommodate authentic undercoat paint chips being mounted on them for subsequent use as undercoat standards in vehicle identifications and comparisons. (The actual selection of chips to be mounted and their use will be described later.)

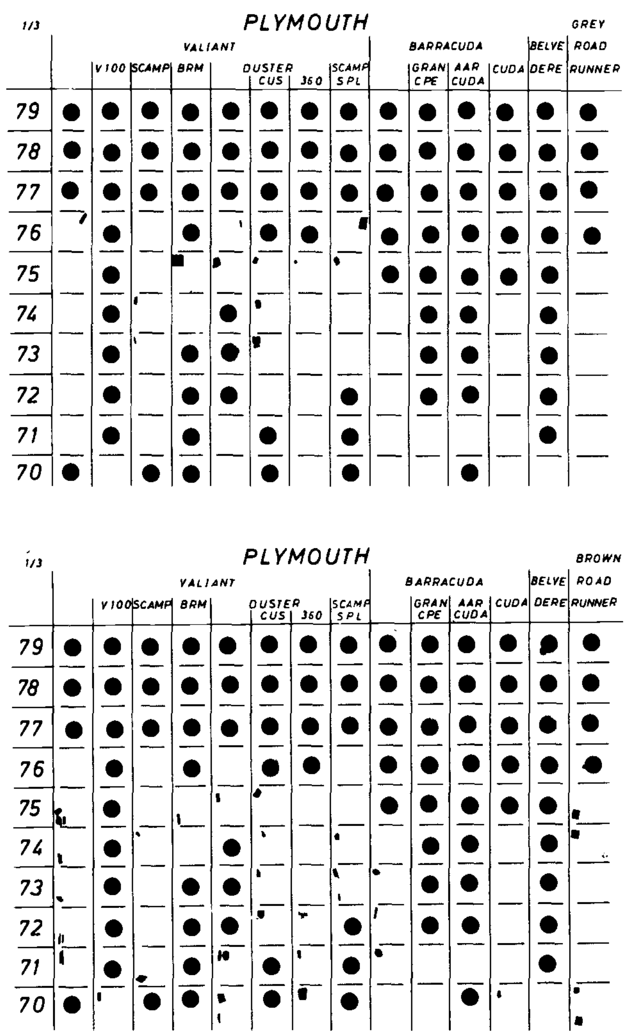


FIG. 4—*Master chip boards.*

Figure 4 illustrates the authentic undercoat standards mounted within the individual squares on the two boards. The color of the undercoat next to the surface substrate determined whether the samples were mounted on the gray or brown board. The position of the sample within each square was determined by the specific assembly plant the vehicle originated from. Blank squares indicate that either a sample for that specific model year and vehicle line/series was not held within the collection or that a sample was mounted on the opposite board. Photostatic copies of the boards were employed to record the SIN and assembly plant information for the undercoat samples. The numbers in the individual squares in Fig. 5 denote the appropriate sequential number portion of the SIN for these standards, while the assembly plants they originated from are noted in Fig. 6. The bottom row in Fig. 6 shows the codes for all the individual plants in which the vehicle line was manufactured for that series of years. It also denotes the positions within each square where the authentic paint samples from the specific assembly plants are to be mounted. The large letters within each

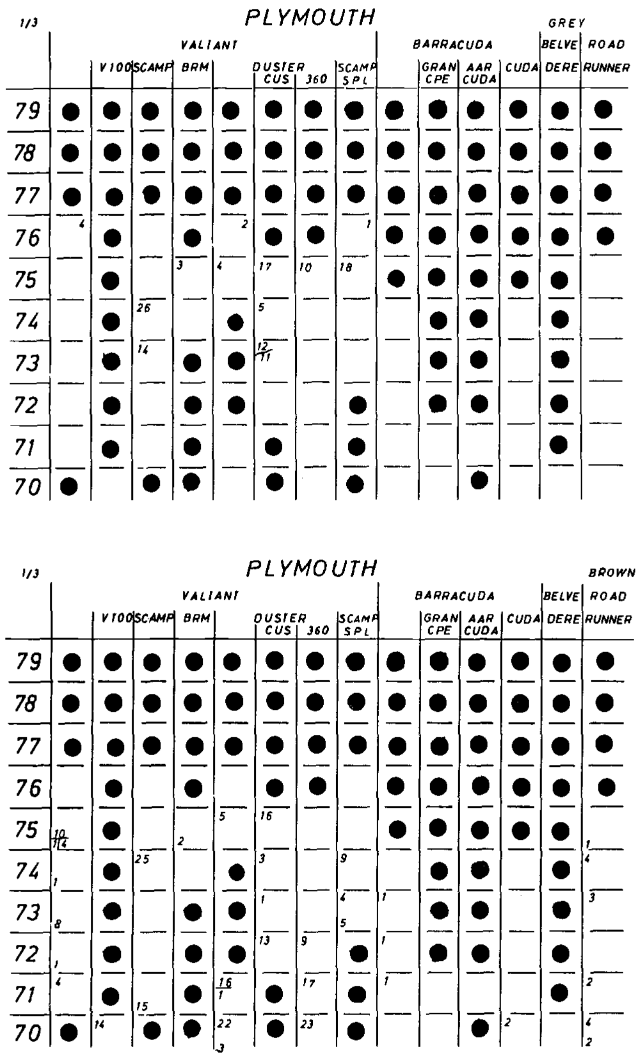


FIG. 5—*Sample identity numbers.*

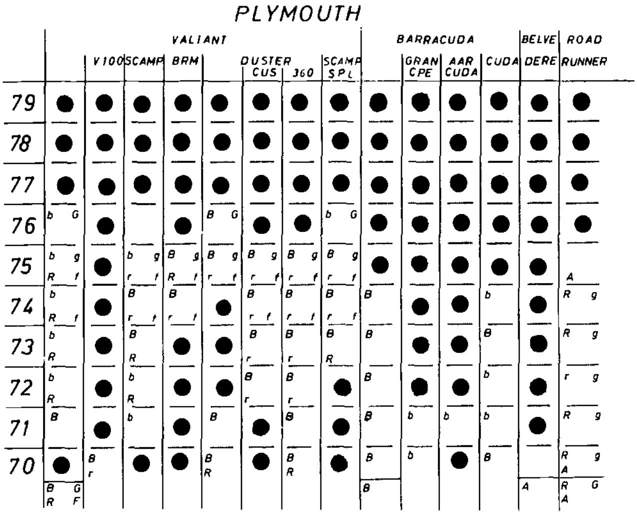


FIG. 6—*Assembly plant data recorded on master chip board.*

square designate the assembly plant of the samples and the SINs represented in Figs. 4 and 5. (The collected samples verified the assembly plant information obtained from the other sources.) The small letters in Fig. 6 indicate that the specific vehicle series was reportedly manufactured in that specific assembly plant but that no standards from street samples are held within the collection.

Microscopic Examinations

Standardized conditions for microscopic comparisons of chromatic and geometric appearances must be precise and reproducible to obtain results comparable with previous inspections. We used accepted industrial standardized conditions as outlined in Refs *26* to *28*.

The collected paint samples were examined with a Leitz stereoscopic microscope (Fig. 1). The paint chips were cross-sectioned with a scalpel so that the total color layer sequence could be recorded. Because the eye becomes more sensitive to very small color differences when samples are adjacent and of the same size, all the samples were placed side by side on the same plane and compared by using either ×10 or ×40 magnification. For the comparisons of the original undercoats the white side of a Kodak neutral test card was employed to assure that a reference background of known reflectance (90%) could always be duplicated.

A fiber optic illuminator (American Optical Model 11-80) equipped with a two-branch, 457-mm (18-in.) long gooseneck light guide was used as the lighting source. To avoid any specular reflection and, hence, lessen the distracting effects of the geometric attributes during color comparisons, the accepted standard lighting/viewing geometry [*26,27*] of 45 deg/normal was adopted with the illuminator adjusted to provide an intense, uniform, extended lighting area. When the geometric attribute differences were assessed, the accepted standard geometry of 45 deg/45 deg was employed to minimize the interference of the color attributes. After the two samples were initially examined, they were rotated 90 deg and reexamined. Their positions were then interchanged and they were reexamined a third time to avoid any bias or "metamerism" in viewing the samples from one direction only.

Although hundreds of thousands of colors can be distinguished, the basic colors of the various topcoats and undercoats were denoted by 11 of the 13 universally accepted basic centroid colors [*29*]. To simplify the basic naming of each paint layer, the centroid colors of olive and yellow-green were not used. However, to accommodate the new clear coats, a color of clear was adopted. Table 2 lists the color names and abbreviations employed within this system. Only black, brown, gray, and white were used to denote the undercoats and an asterisk identified metallic finishes. Body fillers and fiberglass parts were designated by bf and fg, respectively, and repaint undercoats were denoted by (U). Thus, a red metallic topcoat is designated R*, a red body filler by Rbf, and a gray repainted undercoat by Gy(U).

The microscopic examinations were conducted systematically within each manufacturer's category. The specific color layer sequence for each sample was determined and the statistical data concerning color layer sequence, final topcoat color, original topcoat color, total number of topcoats, and total number of layers were recorded in the appropriate files (Figs. 2 and 3). Samples that contained only repainted layers were returned to the files for future analysis.

Where ambiguities arose as to the designation of any specific topcoat color, Leete's system [*30*] and the *Color Information* books by Du Pont of Canada were employed to clarify the situation. In addition, these two topcoat classification systems were used exclusively whenever identification or comparison of original topcoat colors was needed.

The selection of the initial undercoat standards (Fig. 1) mounted on the master chip boards (Fig. 4) for each specific manufacturer was the result of a series of "coring" procedures. All duplicate samples from a specific vehicle series within an individual model year and assembly plant (for example, all thirty 1973 Valiant Dusters manufactured in Hamtramck, Mich.) were compared. For every sample that was completely different from every other sample in both color layer sequence and absolute color of the individual undercoat layers, one undercoat standard was chosen to represent all other samples having the same parameters (Figs. 4 and 5). For instance, even though the corresponding grays were the same, the 73VALI1 sample represents all TC/Gy/Br samples, the 73VALI11 sample all TC/Gy/Br/Bk samples, and the 73VALI12 sample all TC/Gy/Bk. Employing the assembly plant file data (Fig. 6), we mounted these initial undercoat standards for all the vehicle series, undercoat upwards, in the appropriate spot on the master chip board (Fig. 4) with "Micro Lac" adhesive (Micro Instrument Co., Cambridge, Mass., Catalogue No. 535). Their SINs were recorded in the appropriate files (Fig. 5).

To simplify the identification of unknown undercoat paint systems and to facilitate the rapid identification and retrieval of any specific undercoat sequence, a numerical undercoat code system (Fig. 2) was designed. Codes of 1 (gray), 2 (black), 3 (brown), and 4 (white) were combined to produce the appropriate undercoat code for the specific layer sequence. For example, a layer sequence of TC/Gy/Bk/Br would be identified by the undercoat code of 123 and a TC/Gy/Gy/Br sequence would have an undercoat code of 113. For any original undercoat observed, the code was recorded in the appropriate master files for future correlations.

All the initial undercoat standards from a specific model year and assembly plant (for example, all 1973 Plymouth Valiant and Dodge Dart models assembled in Hamtramck) were compared. These samples were then collated and cored as before into a smaller set of secondary undercoat standards that represented all samples of manufacturers' divisions

TABLE 2—*Topcoat and undercoat abbreviations.*

Color	Abbreviation	Color	Abbreviation
Black	Bk	Orange	O
Blue	B	Pink	Pk
Brown	Br	Purple	Pl
Clear	Cl	Red	R
Gray	Gy	White	W
Green	G	Yellow	Y

within a specific plant and year that had identical color layer sequences and absolute color of the individual undercoat layers. Again, where individual undercoat colors were the same but different layer sequences existed, representative samples were retained.

Chemical Analysis

All original topcoat and undercoat layers from the secondary undercoat standards were analyzed by IR (Fig. 1) over the region of 4000 to 200 cm^{-1} with the KBr microtechniques previously described [*25*]. The resultant data were coded into the master coding system described below.

These analyses showed that innumerable undercoat spectra were identical and, as such, it was feasible for one spectrum to represent a series of other spectra. Consequently, the IR spectrum for each undercoat color class (Bk, Br, Gy, and W) was cored into a series of spectra that represented all other identical spectra and were designated as core IR spectra. This saved not only storage space in the master IR files but also time in searching for a specific IR undercoat spectrum.

To correlate all the remaining spectra to these core spectra, a core IR coding system was designed that indicated equivalency between IR spectra of the same color class for the same manufacturer. The ten-character core IR code consisted of the undercoat color abbreviation followed by the manufacturer's code and a spectrum equivalency number. Thus, for example, the codes Br(6-13), Gy(6-10), and Bk(6-2) represent Chrysler Corporation's brown 13, gray 10, and black 2 core IR, respectively. Any other spectrum that was identical to a core IR bore that core IR code (Fig. 2).

To retrieve all the pertinent chemical information rapidly and to facilitate the computerization of the chemical data, a chemical descriptor data coding system was designed (Table 3 and Fig. 2). This coding system employs not only IR data but also X-ray diffraction and elemental analysis (X-ray fluorescence, energy dispersive X-ray fluorescence, or emission spectrographic) data for the individualization of all topcoat and undercoat chemical data. The system consists of three descriptor fields: (1) the resin descriptor field, which identifies the major resin system present; (2) the modifier descriptor field, which identifies the major modifiers to the resin system; and (3) the pigment descriptor field, which identifies the inorganic pigments and elements present within the sample. (The fields within Fig. 2 represent only those used for storing data on factory finishes. Similar fields are employed for storing data on repainted topcoats and undercoats.)

Both the resin and modifier descriptors consist of three-character identity codes (Table 3) denoting the major components identified from the IR analysis [*31*] on any topcoat or undercoat sample. As described elsewhere [*25*], several different repaint topcoat finishes are modified with melamine. The resin descriptor system was designed to differentiate these as alkyd or acrylic repaints and then indicate that they have melamine present by the appropriate modifier descriptor. Original factory alkyd melamine or acrylic melamine finishes are then easily identified as such by the resin descriptor. For example, an original topcoat consisting of a styrene-modified acrylic melamine resin system would be identified with Codes R4 and M1, while an ester-modified epoxy resin undercoat system containing melamine and an unidentified orthophosphate peak (we suspect zinc orthophosphate) would be denoted by Codes R8, M2, and P21 (P22).

The pigment descriptor field consists of a four-character identity code composed of two separate parts: (1) a single-character instrumental descriptor followed by (2) a three-character pigment identity or elemental analysis identity code. The instrumental descriptor designates whether the data were obtained from IR analysis (1), X-ray diffraction analysis (2), or X-ray fluorescence, energy dispersive X-ray fluorescence, or emission spectrographic analysis (3). Where IR or X-ray diffraction analysis was employed to determine the major pigments present, the pigment identity codes outlined in Table 3 were used to denote the

TABLE 3—*Chemical descriptor data coding system.*

Resin Descriptors[a]		Modifier Descriptors[a]		Pigment Descriptors[b]	
Code	Component	Code	Component	Code[c]	Component
R1	alkyd	M1	styrene	P1	TiO_2 (anatase)
R2	alkyd melamine			P2	TiO_2 (rutile)
R3	acrylic	M2	melamine	P3	Fe_2O_3
R4	acrylic melamine	M3	acrylonitrile	P4	ZnO
R5	acrylic melamine (water-based)	M4	benzoguanamine formaldehyde	P5	PbO
R6	acrylic lacquer			P6	Sb_2O_3
R7	epoxy (ester modified)			P7	CN^-
R8	epoxy			P8	CrO_4 = (chromates)
R9	polyester			P9	$ZnCrO_4$ (zinc yellow)
R10	polyurethane			P10	$PbCrO_4$
R11	nitrocellulose			P11	$CaCrO_4$
				P12	$CaCO_3$
				P13	silicates
				P14	silica (amorphous)
				P15	silica (crystalline)
				P16	china clay
				P17	talc
				P18	$BaSO_4$
				P19	$CaSO_4$
				P20	$CaSO_4 \cdot 2H_2O$
				P21	PO_4 = (ortho)
				P22	$Zn(PO_4)_2 \cdot 4H_2O$

[a]IR data only.
[b]Instrumental descriptors designating IR data (1), X-ray diffraction data (2), and X-ray fluorescence, energy-dispersive X-ray fluorescence, or emission spectrographic data (3).
[c]Pigment identity codes only. Elemental analysis identity codes consist of the atomic number of the specific element prefaced by the letter E.

components found. The elemental analysis identity code portion of the pigment descriptor uses information from an emission, X-ray fluorescence, or energy dispersive X-ray fluorescence spectrograph to indicate specific elements within the sample. This three-character code consists of the letter *E* followed by the atomic number of the specific element. Because it is sometimes very difficult to compare quantitatively the elemental analysis data from one laboratory to another, especially when different instruments have been used, no provisions were made to indicate the concentration of the elements found. However, the elemental analysis identity code facilitates the exchange of elemental information independent of the instrument employed.

To illustrate the pigment identity codes: the codes found in Line 1 of Fig. 2 for the Gy(6-10) core IR sample denote that it contained CN^-, china clay, and calcium sulfate, while the codes found in Line 3 indicate both the Gy(6-16) and Bk(6-4) undercoat samples contained barium sulfate and talc. (The Bk [6-4] also contains an unidentified phosphate peak that may be zinc orthophosphate [P22].) The corresponding pigment descriptor elemental analysis identity codes would be 3E13, 3E14, 3E20 and 3E12, 3E14, 3E56, respectively.

Core Undercoat Standards

After the chemical analysis was completed, the secondary undercoat standards were microscopically compared to correlate the data from all assembly plants and model years. To obtain a set of daily working samples, a final set of core undercoat standards (Fig. 1) was chosen by using all the information from the correlated microscopic and chemical data. A core descriptor denoted by an asterisk was placed beside the SIN (Fig. 2) to indicate a core undercoat standard. Although portions of the microscopic or chemical data could be common to several core standards, each standard had a unique combination of microscopic and chemical data. All other original undercoat samples within the data system were assigned an undercoat equivalency number (Fig. 2) consisting of the SIN of the core standard to which it was equivalent. Thus, every original sample within the files was indexed to a particular core undercoat standard.

For each manufacturer, the final core undercoat standards were assigned a core board position number (Fig. 2) and the sample was mounted onto a core chip board. These core chip boards consisted of Kodak neutral test cards onto which was drafted a 1- by 1-cm grid system. Each board bore the manufacturer's name and consisted of a series of columns and rows designating the specific coordinates for each sample. The core board position number assigned to each core undercoat standard was composed of a three-character field designating the location of the sample. Thus, for example, A10 and E02 designated core Sample 10 in Row A and core Sample 2 in Row E. The core chip boards then became the daily working boards for all microscopic comparisons and identifications of paint samples.

Finally, each undercoat layer from all the core standards was coded into the Munsell color system [*32*] and recorded in the master files (Fig. 2) to facilitate access to the data banks via computer from either core board position or Munsell coordinates. In addition, the data from Leete's new reference collection on automotive undercoat systems will be correlated to the data system. The Munsell coordinates were entered into this data system *solely* to facilitate a rapid initial search of the data files to locate the core undercoat standards. Once a series of possible samples has been identified, the final comparisons are always conducted on the core standards. Thus, no interpolation between the colors in the Munsell matte finish book was carried out. The undercoat colors were simply matched to the closest color found in the Munsell collection, the coordinates recorded, and searching limits of ± 2.5 hue, ± 1 value, and ± 2 chroma established for all readings. These limits adequately accounted for any variances among examiners, laboratories, and viewing conditions so that the correct core undercoat standard could always be obtained from the data system.

Discussion

The human eye is an extremely sensitive and discriminating sensor, and thus, for the forensic chemist, the microscopic examination of paint samples remains the most important link in paint identification and comparison. However, there are some problems associated with developing a universal color coding system. The Intersociety Color Council-National Bureau of Standards, Hunter, Munsell, and Methuen uniform color systems do exist, but their applications for forensic science purposes have been very limited because no best scale exists for automotive paint comparisons. The best color scale would be the one that most closely duplicates the visual situation encountered, and some of the color systems are better than others for specific forensic science applications. The classification system that has been developed within this laboratory shares none of the limitations of the commercially available color coding systems. No arbitrary scales exist because all the final comparisons are done by using undercoat colors and sequences that are actually original automotive finishes and, therefore, for its designed use this system is extremely specific.

A great deal of experimentation and evaluation of standard conditions for lighting, backgrounds, viewing angles, and the other variables that affect visual color difference evaluations were conducted on our paint standards. Because of the close association between chromatic and spatial attributes, the human eye does not normally segregate between the two. The various paint layers are normally perceived in terms of either a color (blue, white, brown, and so on) or in terms of the color components of hue, saturation, and brightness [*33*]. However, intimately involved in the comparison of two paint chips are the differences perceived because of different geometric attributes such as gloss, texture, haze, clarity, and opacity. A difference in gloss, such as a change in luster, sheen, or distinctness of image, may influence the judgment of color differences, even though the differences in gloss may be minimized by the diffuse nature of the surroundings.

It was therefore imperative to recognize that the overall perception of paint chips was influenced not only by the color of the various layers but also by how the perceived light varied from point to point across the surface of the layers. The color was seen as a result of diffuse reflection through the interaction of the colored pigments absorbing the light and the titanium dioxide and other white pigments scattering or diffusing the light. The resin to pigment ratio and the paint surface structure greatly affected the specular reflection which, in turn, affected the geometric attributes of gloss, texture, and so on. With the introduction of metallic finishes and clear coats, it became increasingly important to recognize the metameric effects created because of the differences in geometric attributes, especially gloss. For instance, a brilliantly colored "topflash" was perceived at normal illumination and viewing while a hue or chroma shift with the loss of metallic particles was observed on oblique viewing or "downflop." This was a result of the size distribution of the metal particles being used to control the chroma difference between topflash and downflop [*9,34,35*].

While the samples were being sorted into a set of working standards, it became obvious that the surface geometric attributes played a major role in the identification and comparison of those samples. Because of the slight microscopic variances found across the metal surfaces as a result of manufacturing or repair processes, the differences in the gloss and texture of the undercoat surfaces next to the substrate were found to be very significant. When paint samples from the same model year and assembly plant were compared, a wide variance in the gloss and texture was observed. These "accidental characteristics" proved very useful for comparison purposes. However, when the core undercoat standards were used for the identification of unknown paint samples, the geometric attributes of the undercoat surface had to be eliminated or minimized to ensure that only the chromic attributes were being compared.

It also bears noting that a considerable amount of experimentation was conducted with the Munsell system to ensure that the Munsell coordinates could be obtained reproducibly.

Attempts were made to view the paint chips and the Munsell colors under a Leitz comparison microscope. However, it was found that the positions of the individual gooseneck light guides on the fiber optic illuminator were extremely critical. No matter how carefully the positions of the guides were controlled, it was not possible to completely balance the lighting conditions. One side or the other of the comparison microscope consistently imparted a gray color. This shifted the color of one sample diagonally upwards or downwards in value and chroma [*28*] when the paint chip and Munsell color chips were interchanged. As a consequence, all the Munsell colors were recorded under viewing conditions identical to those previously described for the microscopic examination of the paint chips. This ensured that both samples were under identical lighting conditions and therefore the lighting conditions became less critical for the exchange of information between laboratories.

The individual colors of the undercoats originating from a particular assembly plant within the same model year should have the same chemical composition as determined by IR, providing there has been no change in the primary vendor of the paint. As a double check, IR chemical analyses were conducted on all secondary undercoat standards, thus ensuring that a completely representative set of core undercoat standards would be chosen. When different IR spectra were observed on samples having the same undercoat colors, all those samples were included in the core data and will be described in subsequent papers.

The elemental analysis of all the core undercoat standards will be conducted with X-ray fluorescence techniques; however, this will be left until all the microscopic and IR chemical data are completed and computerized to ensure that the data retrieval system is functional within the shortest possible time.

The data retrieval system (Fig. 2) and the master chip board records (Figs. 4-6) are now being computerized. This will facilitate the very rapid and systematic retrieval of information by many methods for the identification and comparison of paint samples. Constant updating of information can be readily facilitated as vehicle lines/series are added to or deleted from a manufacturer's sales lines. Automotive manufacturers' and paint vendors' data can also be accommodated. All this information is very valuable in determining missing data required for updating the paint standard collection.

Although the manual mode is relatively slow, the data retrieval system facilitates a systematic search for the determination of a limited series of vehicle lines/series, model years, and assembly plants for unknown paint chips bearing original topcoat and undercoat systems [*36*]. A simple microscopic examination of paint samples determines the undercoat layer sequence and, by accessing only the core samples with the core descriptor and undercoat codes (Fig. 2), the data retrieval system can be rapidly searched. All core samples from all manufacturers that have the same undercoat codes will be identified by their manufacturer's code, SIN, core board position, and core IR descriptors. The same information can be obtained through the Munsell coordinates for each undercoat layer. A third alternative is to determine the manufacturer and years of a topcoat color from the Du Pont or National Bureau of Standards collection and, with the appropriate manufacturer's code and undercoat or Munsell codes, search the data system to identify the SIN, core board position, and core IR data for samples that match the parameters entered.

Accessing the data system for an identification of an unknown is not restricted to the microscopic data. If any of the chemical compositions on the topcoats or undercoats have been determined, the system can be searched by using the chemical data descriptors (Table 3) to produce the appropriate SIN, manufacturer's code, core board position, and core IR.

The most specific query method would certainly be to use all the microscopic and chemical data to identify a very narrow set of core samples. By comparing the undercoat colors of the unknown sample to the identified core undercoat standards and comparing the chemical data to the corresponding core IR spectra, the unknown would be rapidly identified.

Once the data retrieval system has aided in identifying a limited series of core standards, it can then be reaccessed to determine the assembly plant, area on the vehicle, number of other identical noncore samples (through the undercoat equivalency numbers or core IR descriptors) or any other information (such as factory or paint vendor's data) pertinent to the investigation. The analyst could access the master chip board data files to determine the specific vehicle series made in any particular year (Figs. 4 and 6). This information would be valuable in determining the applicable partial VINs and relaying this information to an investigator. Only the appropriate partial VINs as determined from the National Auto Theft Bureau books would have to be searched on the motor vehicle branch computers to determine the registered owners within a specific area. This would eliminate excessive searching time for the computer and investigator.

The collection of the 10 000 paint samples produced some unexpected but understandable results. Not all vehicle series from any one particular assembly plant for a specific vehicle line were shipped into and registered within Alberta. The economics of shipping and marketing is important for manufacturers and consequently indirectly affects our analyses. Figure 6 illustrates the marketing procedure very clearly. Although the Valiant and Valiant Duster series are manufactured in both Windsor, Ont. and Hamtramck, Mich., it became apparent after we collected 30 to 40 samples of each vehicle series that within our area the Valiant series was normally shipped from Windsor while the Valiant Dusters were shipped from Hamtramck. In addition, both series were manufactured in Newark, Del., in 1974 and 1975, but no vehicles from that plant were sampled in our area. These marketing factors play a large role in determining the partial VIN and model information used to determine the registered owners of hit-and-run vehicles.

The statistical data obtained from this collection of paint samples have also provided a data bank that can be accessed for frequency distribution data. Data on topcoat colors; original topcoat colors; total number of topcoats, undercoats, and layers; and number of repaints or originals as well as specific layer sequences (Fig. 2) have been correlated to the number and type of vehicles involved in accidents. By obtaining motor vehicle branch data, manufacturers' data, and data from such sources as the "Marketing Data Book Issue" of *Automotive News*, the number and types of vehicles currently in use will be statistically related to the data bank and will be presented in subsequent papers.

The data retrieval files are important in the comparison of paint samples. Not only can the forensic scientist determine that the known and unknown paint samples had the same physical appearances and chemical compositions, but, by accessing both the core and noncore data files, he also can select all the pertinent statistical information required to indicate the individuality a particular paint comparison has within any given investigation. Although every paint comparison produces different results, the usefulness of this data can be illustrated as follows: suppose the analysis involved a comparison of paint chips composed of a red topcoat with a gray/brown undercoat system. If the paint chips were original motor vehicle finishes, the forensic scientist could determine from the data retrieval files that the samples originated from, for example, a 1974 Plymouth Valiant manufactured in Windsor, Ont. Information from the statistical data bank would then indicate that only 16 of the 11 500 samples were from 1974 Valiants bearing three layers of paint and of these 16 only 5 originated from the Windsor assembly plant. The motor vehicle branch data would indicate that less than 2% of the 2.4 million vehicles in Alberta are Plymouth Valiants and approximately 500 vehicles are red 1974 Valiants manufactured in Windsor. By presenting all this information along with the microscopic, chemical, and other frequency distribution data to the court, the significance of this particular paint analysis would be clearly indicated.

The subsequent papers in this series will present the microscopic, chemical, and statistical data obtained from our comprehensive classification system for the identification and comparison of paint from motor vehicles involved in accidents.

References

[*1*] Fouweather, C., May, R. W., and Porter, J., *Journal of Forensic Sciences*, Vol. 21, No. 3, July 1976, pp. 629-635.
[*2*] *Methuen Handbook of Color*, Eyre Methuen Ltd., North Way, Andover, Hampshire, Great Britain, 1978.
[*3*] Hudson, G. D., Andahl, R. O., and Butcher, S. J., *Journal of the Forensic Science Society*, Vol. 17, No. 1, 1977, pp. 27-32.
[*4*] Tippett, C. F., *Medicine, Science and the Law*, Vol. 4, 1964, pp. 22-25.
[*5*] Cleverley, B., *New Zealand Journal of Soil Science*, Vol. 10, No. 2, 1967, pp. 556-562.
[*6*] Cleverley, B., *Journal of the Forensic Science Society*, Vol. 10, No. 2, 1970, pp. 73-76.
[*7*] Deaken, D., *Journal of Forensic Sciences*, Vol. 20, No. 2, April 1975, pp. 283-287.
[*8*] Beckwith, N. P., *Paint and Varnish Production*, Vol. 63, No. 4, 1973, pp. 15-20.
[*9*] Williams, R. A., *Automotive Finishes, Unit 25*, Federation of Societies for Coatings Technology, Philadelphia, 1977.
[*10*] Rodgers, P. G., Cameron, R., Cartwright, N. S., Clark, W. H., Deak, J. S., and Norman, E. W. W., *Canadian Society of Forensic Science Journal*, Vol. 9, No. 1, 1976, pp. 1-14.
[*11*] Rodgers, P. G., Cameron, R., Cartwright, N. S., Clark, W. H., Deak, J. S., and Norman, E. W. W., *Canadian Society of Forensic Science Journal*, Vol. 9, No. 2, 1976, pp. 49-68.
[*12*] Rodgers, P. G., Cameron, R., Cartwright, N. S., Clark, W. H., Deak, J. S., and Norman, E. W. W., *Canadian Society of Forensic Science Journal*, Vol. 9, No. 3, 1976, pp. 103-111.
[*13*] Steward, W. D., *Journal of Forensic Sciences*, Vol. 19, No. 1, 1974, pp. 121-129.
[*14*] Steward, W. D., *Journal of the Association of Official Analytical Chemists*, Vol. 59, No. 1, 1976, pp. 35-41.
[*15*] Wheals, B. B. and Noble, W., *Journal of the Forensic Science Society*, Vol. 14, No. 1, 1974, pp. 23-32.
[*16*] Hueske, E. E. and Clodfelter, R. W., *Journal of Forensic Sciences*, Vol. 22, No. 3, July 1977, pp. 636-638.
[*17*] Manura, J. J. and Saferstein, R., *Journal of the Association of Official Analytical Chemists*, Vol. 56, No. 5, 1973, pp. 1227-1233.
[*18*] Reeve, V. and Keener, T., *Journal of Forensic Sciences*, Vol. 21, No. 4, Oct. 1976, pp. 883-907.
[*19*] Haag, L. C., *Journal of the Forensic Science Society*, Vol. 16, No. 3, 1976, pp. 255-263.
[*20*] Meinhold, R. H. and Sharp, R. M., *Journal of Forensic Sciences*, Vol. 23, No. 2, April 1978, pp. 274-282.
[*21*] West, J. C., *X-ray Spectrometry*, Vol. 4, No. 1, 1975, pp. 71-73.
[*22*] Tippett, C. F., *Medicine, Science and the Law*, Vol. 4, 1964, pp. 91-97.
[*23*] Gothard, J. A., *Journal of Forensic Sciences*, Vol. 21, No. 3, July 1976, pp. 636-641.
[*24*] Cartwright, N. S. and Rodgers, P. G., *Canadian Society of Forensic Science Journal*, Vol. 9, No. 4, 1976, pp. 145-154.
[*25*] Percy, R. F. E. and Audette, R. J., "Automotive Repaints: Just a New Look?" *Journal of Forensic Sciences*, Vol. 25, No. 1, Jan. 1980, in press.
[*26*] Hunter, R. S., *The Measurement of Appearance*, Wiley-Interscience, New York, 1975.
[*27*] Billmeyer, F. W., in *Industrial Color Technology*, American Chemical Society Advances in Chemistry Series, No. 107, Washington, D.C., 1971, pp. 23-42.
[*28*] Evans, R. M., in *Industrial Color Technology*, American Chemical Society Advances in Chemistry Series, No. 107, Washington, D.C., 1971, pp. 43-68.
[*29*] Kelly, K. L. and Judd, D. B., "Color-Universal Language and Dictionary of Names," National Bureau of Standards Special Publication 440, Washington, D.C., 1976.
[*30*] Leete, C. G., "Reference Collection of Automotive Paints," National Bureau of Standards, Washington, D.C.
[*31*] "Infrared Spectroscopy. Its Use in the Coatings Industry," Federation of Societies for Paint Technology, Philadelphia, Pa., 1969.
[*32*] *Munsell Book of Color*, Matte Finish Collection, Macbeth Division of Kollmorgan Corp., Baltimore, Md., 1976.
[*33*] Johnston, R. M., in *Industrial Color Technology*, American Chemical Society Advances in Chemistry Series, No. 107, Washington, D.C., 1971, pp. 2-16.
[*34*] Foster, R. S., in *Industrial Color Technology*, American Chemical Society Advances in Chemistry Series, No. 107, Washington, D.C., 1971, pp. 17-22.

[35] Huey, S. J., in *Industrial Color Technology*, American Chemical Society Advances in Chemistry Series, No. 107, Washington, D.C., 1971, pp. 146-170.
[36] Audette, R. J. and Percy, R. F. E., *R.C.M.P. Gazette*, Vol. 40, No. 12, 1978, pp. 26-27.

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