Applications

Introduction

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Ink and Printing Sample Preparation Notes

Many color matching problems can be avoided by careful sample preparation. The following guidelines should help accomplish this:

- Collect standard lots of colorants to proof, using them for the primary calibrations.
- Determine "standard" printing conditions, viscosity, tack, etc., then measure and control these conditions accurately.
- Collect accurate physical data (weights, densities, formula percentages).
- Weigh accurately, and record the actual weights of colorants mixed and proofed.
- Proof using a reproducible proofing device and technique.
- Proof an ink mixture a number of times, and measure color differences between proofs to check reproducibility of the process.
- Use a single lot of clean, bright, NON-ABSORBING, NON-OPTICALLY-WHITENED, contrast ratio charts as the substrate for primary calibrations.
- When mixing colorants with white, do this at the pigment loading typical of most products.
- Remember that additional whites may be stored at different white pigment loadings.
- The substrate for the primary calibrations should be the same as used to test most production. If different production substrates are typically used, try to group them according to their absorption. It may be necessary to calibrate different Colorant Sets for different substrates, if the substrates significantly alter color results (from the calibration substrate).
- When storing the primary calibration substrate, measure and store both the black and white “backgrounds”.
- If samples appear inconsistent, take multiple instrument reads, to average over a larger sample area.
- If a sample bronzes, varnish it. Sphere specular included viewing geometry "sees" bronzed samples differently than the eye; however, overprinting with varnish reduces this effect.

Sample Preparation Guide

This guide contains basic instructions to help you prepare a colorant database for use with Datacolor International's advanced color matching, correction, palette and recycle technologies. Please read it in it's entirety before starting.

By necessity, the following guidelines are general. Some changes may be necessary for individual processes.

Before preparing a new database, you should discuss your process and your requirements with a Datacolor International Application Specialist.

We at Datacolor International are proud of our reputation for the best computer color matching results in the world. We want you, as our partner in this technology, to share in this pride.
As a Datacolor International customer, you are assigned a specialist from your industry, someone who can speak "your language", who is eager to work with you via telephone or in person to help you get the best computer color matching results in the world.
Since we could not include specific instructions in this guide for every variation in ink and printing processes, here is a list of situations for which we would like to give you additional or special information. If your process or materials fit into any of the following categories, please contact your ink and printing application specialist in our technical support department. Our toll-free telephone number is on the front of this guide.

You may not need to make all the proofs listed in this guide if:

- you never use a pigmented white in any of your formulas
- you always use a pigmented white in every formula
- your ink always prints completely opaque

You may need to make additional samples, not listed in this guide if:

- You print only on absorbent substrates
- You print only on transparent substrates (first or second surface)
- You print only on metallic substrates

Introduction

These instructions will help you to prepare a set of proofs which represent your primary colorants to a Datacolor International computerized color formulation system. If you have any questions, please contact DCI to speak to an ink and printing industry specialist.

Before You Begin

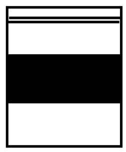
Your ability to repeatedly produce the same color from a given formula is vital to your success in computer color matching. Before reading any further, look around your laboratory and production area for sources of variation. Your proofers, scales, mixers, viscometers and procedures all contribute to variations in your final proofs.

What You Will Need

Raw Materials:

- You will want to collect standard lots of all your raw materials. That includes inks, pigments, resins, varnishes, extenders, solvents, overprints, additives...anything that will be in your final product. If you cannot get "standard" lots, try to identify lots or batches that represent the materials most commonly used in production.
- Standard lot samples of your most commonly used substrate
- Some black and white contrast ratio charts

Important Tip: *Be sure the contrast ratio charts do not contain optical (fluorescent) brightners and that they do not absorb your ink.*



Equipment:

- Accurate scales for weighing inks and extenders
- A density cup for measuring weight per volume
- For fluid inks: an accurate viscometer
- A repeatable proofer

Tip: *A list of equipment suppliers is in back of this guide.*

Terms Used In This Guide

The following words have specific meanings when used in this guide and in Datacolor programs. Even though The programs allow you to change these default names, in this guide we will use the following names.

Ready to Print - Nothing needs to be added to the ink before printing.

Density - A measure of weight per volume. Common units are pounds per gallon or grams per liter. Rather than specific gravity, try to use weight and volume units common in your process. For example, if you buy ink by the gallon and your scales read in pounds, use lb./gal as your measure of density. Here, density does *not* refer to colorimetric or printing density.

Contrast Ratio Chart - A type of substrate that has both a white and a black area. It is used to measure the opacity (light scattering) of ink films. You should select a type of black and white stock which absorbs your ink as little as possible.

Component -A raw material. The program can provide predicted formulas with colorants and extender amount broken down into their component raw materials. You must provide the “component recipe” for individual colorants.

An example: A ready-to-print white ink is made of 500 grams of a concentrated white base plus 700 grams of clear resin, 200 grams of thinner (water) and 100 grams of a wax compound.

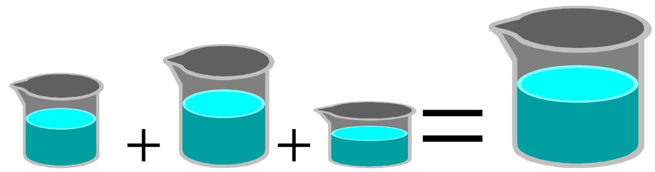
The concentrated white base, the resin, the water and the wax are components of the white colorant.

Ready to Print Formula		Expanded Formula	
White	50	Concentrated White Base	33.3
Extender	50	Clear Resin	46.7
Total	100	Water	13.3
		Wax	6.7
		Extender	50.0
		Total	100

How To Begin

- First you must choose your standard press-ready conditions. For some, this is easy -- their inks are ready to use as they buy them. Others will need to choose a standard press viscosity or tack.
- Once you know what your standard press-ready conditions are, take your colorants, one at a time, and make them into a ready-to-print ink. To each colorant, add whatever components are necessary to turn it into a finished ink -- completely ready to print. Add whatever vehicle, solvent, wax, thinner, drier... to bring it to press-ready viscosity or tack. Do the same thing with your extenders or clears.
- While you are mixing your colorants, and components, you must carefully record the weight of each component in the mixture.
- After your colorants and extenders are press-ready, you should measure the density (weight per volume) of each as accurately as possible and record the number. You must also know the density (weight per volume) of each component.

Here is an example:



100 g **150 g** **50 g** **300 g**

BLUE CLEAR THINNER Ready to Print

Starting with a known weight of a blue concentrate, we add the minimum amount of resin needed to make it printable. In this case, 150 grams of clear vehicle are required. Next, we add enough solvent to bring the ink to our standard press-ready viscosity. In this case, it takes 50 grams of solvent. After mixing the press ready ink, we measure its density at 7.12 lb./gal.

The worksheets on the following pages will help you remember and record the appropriate information for each colorant and component. COLORANT PROOFS
After each colorant and extender is brought to press-ready, you are ready to begin making and collecting your proofs. From here on, in this guide all references to any colorant or extender refer to the press-ready mixtures you made in the previous steps.
Use the worksheets on the next pages to help you keep track.

SUBSTRATES: You will need two types. First, a commonly used production substrate and second a non-absorbing, non-optically-brightened, black and white substrate. We use the black and white substrate for measuring the opacity of your inks. It is important that you select a type of contrast ratio chart into which your inks will NOT absorb.

EXTENDER: You will need proofs of your extender by itself on both types of substrates depending on the clear's optical properties.

WHITE: One print of your white is required on your contrast ratio charts. We suggest making three additional prints at various loadings. First your press-ready white by itself and then mixed with additional press-ready extender. Select a range of typical extender loadings to cover the range of white percentages you normally use in production.

BLACK: You may make up to twenty black mixtures. Some must be on black and white substrate (Contrast Ratio) while others may be on your production substrate(s). Select a range of black and extender loadings to cover your typical production use.

- Up to ten (10) mixes of black and extender on a typical production substrate.
- Up to ten mixes of black and white on Contrast Ratio Charts.

ALL OTHER COLORANTS: You may make up to twenty colorant mixtures. Mixes with black and white must be on a black and white substrate. Mixes with extender may be proofed on a typical production substrate.

- Up to ten (10) mixes of colorant and extender on a typical production substrate

- One mix of colorant and black on Contrast Ratio Charts
- Up to nine (9) proofs of colorant mixed with white on Contrast Ratio Charts

Important Tip *You will not improve your color matching results by weighing suggested percentages exactly. You will improve your results by accurately weighing what you do use. To speed things up, just get close to these percentages and then record the weighed amount on the following worksheets as accurately as you can.*

Ink Sample Preparation Worksheet #1

Complete the Substrate, Extender and Components charts once for each colorant data file.

Substrates:

Sample	Substrate Name	Description
		Contrast Ratio (Black&White)
		Typical Production Substrate

Ink Sample Preparation Worksheet #1

Extender:

Extender Name	Other (Visc/Tack)	Density (Wt/Vol)	Cost
Extender Proofs			
Proof on Typlical production Substrate			
Proof on contrast ratio (black&white)			
Extender Components	**Amount**	**Density**	**Cost**

Ink Sample Preparation Worksheet #1

Other Components: (Thinner, Wax, Drier..)

Other Components Names	Other (Visc/Tack)	Density (Wt/vol)	Cost

Ink Sample Preparation Worksheet #2

Complete this chart for each colorant data file.

White Primary: (Calibrating White)

White Name	**Other (visc/Tack)**	**Density (Wt/vol)**	**Cost**
White Components	**Amount**	**Density**	**Cost**
White Proofs on Contrast Ratio Substrate (White&Black)	**White Amount**	**Extender Amount**	**Units**
100% White on CR Substrate			
About 80% White 20% Extender on CR			
About 50% White 50% Extender on CR			
About 20% White 80% Extender on CR			

Ink Sample Preparation Worksheet #3

Complete this chart for each colorant data file.

Black Primary: (Calibrating Black)

Black Name	**Other (visc/Tack)**	**Density (Wt/vol)**	**Cost**
Black Components	**Amount**	**Density**	**Cost**

Black Proofs	**Black Amount**	**Extender Amount**	**White Amount**
100%Black on CR			
About 80% Black 20% White on CR			
About 50% White 50% Extender on CR			
About 20% Black 80% White on CR			
About 10% Black 90% White on CR			
About 5 Black 95% White on CR			

100% Black on Production Substrate			
About 80% Black 20% Extender on PS			
About 60% Black 40% Extender on PS			
About 40% Black 60% Extender on PS			
About 20% Black 80% Extender on PS			
About 10% Black 90% Extender on PS			
About 5% Black 95% Extender on PS			

About 2% Black 98% Extender on PS			
About 1% Black 99% Extender on PS			
About 0.5% Black 99.5% Extender on PS			

INK SAMPLE PREPARATION WORKSHEET

Complete this chart once for each additional colorant.

Colorants:

Colorant Name	**Other (visc/Tack)**	**Density (Wt/vol)**	**Cost**
Colorant Components	**Amount**	**Density**	**Cost**
Colorant Proofs	**Colorant Amount**	**Extende r Amount**	**White Amount**
100% Colorant on CR			
About 95% Colorant 5% Black on CR			Black
About 80% Colorant 20% White on CR			
About 50% Colorant 50% White on CR			
About 20% Colorant 80% White on CR			
About 10% Colorant 90%			

White on CR			

About 5% Colorant 95% White on CR			
100% Black on Production Substrate			
About 80% Colorant 20% Extender on PS			
About 60% Colorant 40% Extender on PS			
About 40% Colorant 60% Extender on PS			
About 20% Colorant 80% Extender on PS			
About 10% Colorant 90% Extender on PS			
About 5% Colorant 95% Extender on PS			
About 2% Colorant 98% Extender on PS			
About 1% Colorant 99% Extender on PS			
About 0.5% Colorant 99.5% Extender on PS			

PREPARING FOR A DCI USERS COURSE

During an Ink and Printing Users' Course at Datacolor International, you will use the proofs you have made to build a small database of primary colorants. You do not need to make proofs of all your colorants, but you will need to make samples for at least three colorants. We recommend that you select your most commonly used RED, YELLOW and BLUE colorants in addition to WHITE, BLACK and EXTENDER.

Since you cannot bring your wet inks and laboratory with you to class, to test your new database, you will use the following "known formulas" .   You will also use formulas 9 and 10 to determine the variation in your weighing, mixing and proofing processes.

WHAT TO DO:

- Weigh and proof known mixes 1 thru 8 one time each.
- Weigh known mix 9 once but make five proofs.
- Weigh known mix 10 three times and make one proof of each weighing (three proofs).

Known Mix	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Black	1	2	1	-	-	1	2	5	-	-
Red	4	10	-	3	15	5	40	-	5	10
Yellow	15	-	30	12	2	10	-	40	10	20
Blue	-	13	4	10	3	-	40	10	20	2
White	80	75	50	70	75	-	-	-	-	-
Extender	0	0	15	5	5	84	18	45	65	68
Substrate	cr	cr	cr	cr	cr	tp	tp	tp	tp	tp

CR = Contrast Ratio Chart; TP = Typical Production Substrate

A Users Course check list

Before coming to an ink users' course be sure you have all this ready:

☐ A completed copy of Worksheet #1
☐ A completed copy of Worksheet #2
☐ A completed copy of Worksheet #3
☐ A completed Worksheet for RED
☐ A completed Worksheet for BLUE
☐ A completed Worksheet for YELLOW
☐ Two (2) substrate samples
☐ A set of four (4) White proofs
☐ A set of sixteen (16) Black Proofs
☐ A set of seventeen (17) Red Proofs
☐ A set of seventeen (17) Yellow Proofs
☐ A set of seventeen (17) Blue proofs
☐ One (1) proof each of Known Mixes 1, 2, 3, 4, 5, 6, 7 and 8
☐ Five (5) proofs of Known Mix 9 (weighed one time)
☐ Three (3) proofs of Known Mix 10 (re-weighed three times)

Special Situations

SURFACE EFFECTS Bronzing, haze, dry-hide, reflex . . are names used to describe surface effects caused by high (or over) pigmentation. If not properly identified and controlled, your color-matching results will suffer. We recommend over-printing (varnishing) the bronzed prints with your extender. An example of bronzing is the red cast seen at the surface of a reflex blue.

METALLIC/PEARLESCENT PIGMENTS If you routinely use metallic or pearlescent flake pigments in your inks, we have a number of special application techniques and options you can use to insure good color matching results. Please call us toll-free at the technical support number listed on the front of this guide to speak with an ink and printing industry specialist.

NATURAL KRAFT PAPER If you routinely use colored, very absorbent paper or carton stock as a substrate, please call our technical support line to discuss sample preparation with an ink and printing industry specialist before you begin.

Proofers

Using more consistent proofers, you can achieve better color matching results. Usually, the more automated the proofer, the better. If you must use a manual proofing device, please call Datacolor Technical Support to discuss techniques to improve repeatability.

Anilox Not recommended Hand held proofer, is convenient but extremely operator dependent.

Geiger -Fair Acceptable for gravure with proper technique. Printing from an engraved cylinder gives fair short-term and better long-term repeatability. Requires a relatively large (4 oz) ink sample. Clean up is time consuming.

K-Coater Good for gravure, flexo or coatings. Wire-wound bars, mechanically driven make for easy cleaning. Short-term repeatability is good. Longer-term repeatability degrades as bars age. The etched-plate gravure attachment gives worse short-term and better long-term repeatability. Determining bar speed and pressure to match production film thickness requires some experimentation.

Quick Peek Not Recommended In this extremely operator-dependent technique, roughly measured ink is hand rolled and transferred to substrate via the roller.

Little Joe Fair Acceptable for offset depending on inking technique. A etched wedge plate and accurate pipette is required for best results. Special techniques are required to obtain the best batch correction results.

Prufbau Very Good For offset inks the Prufbau delivers excellent short and long-term repeatability. This expensive proofer is very reliable and delivers high-quality prints. Clean-up time, while longer is not excessive.

Reprotest Very Good for offset, gravure and flexo. The basic model is gravity driven. An inking unit (and its clean up) is required for paste inks. For fluid inks, the gravure and flexo models provide moderately easy cleaning and good reproducibility. This proofer delivers good quality gravure and flexo proofs.

Saueressig Good for gravure or flexo. Hand or electrically powered, it prints from an engraved cylinder onto a flat bed in 3.5 and 7 inch widths. Good reproducibility with fairly easy cleanup.

Wire Bars **Not Recommended** Draw downs from hand held, wire-wound bars are extremely user dependent.

Precision Proofer **Very Good** for flexo. A mechanical arm moves a hand-held Anilox roller. Easy to operate with quick clean-up.

Suppliers

K-Coater
McCullough & Benton, PO Box 29803, Atlanta, GA 30359,
Tel#: (404) 325-1606

Testing Machines Inc. (TMI) 400 Bayview Ave.,Amityville, NY 11701, Tel#: (516) 842-5400

Little Joe
Little Joe Color Swatcher, Inc, Building 6, Unit 15, Ilene Court
Belle Mead, NJ 08502, Tel#: (908) 526-5320

Precision Gauge and Tool, 28 Volkinand Ave., Dayton, OH 45435

Saueressig Detweiler, 310 Oser Ave., Hauppauge, NY 11788

Geiger Geiger Tool & Mfg Co, 50 Liberty Street, Passaic, NJ 07055

SA Lab Screen Press Systematic Automation, 109 West Dudley Town Road, Bloomfield, CT 06002, Tel#: (203) 242-2922

Precision Proofer Pamarco, 209 East 11th Avenue, Roselle, NJ 07203
Tel#: (908) 241-4009

Contrast Ratio Charts The Leneta Company, P.O. Box 86, Ho-Ho-Kus, NJ 07423, Tel#: (201) 825-7855

Density/Spec. Gravity Cup Comsler Scientific Design. P.O. Box 1084
Oldsmar, FL 33557, Tel#: (813) 855-5736

Datacolor International makes no claim or warranty as to the above suppliers or their products. This list is provided as a service to our customers.

Ink & Printing - Differences in Film Thickness

How can differences in film thickness produced by different printing methods be quantified?

Proofing the same ink by different methods or on different equipment should yield proofs which can be evaluated for strength differences. For transparent ink, the difference in strength from proof to proof may be assumed to be equal to the film thickness differences.

The more transparent the ink films the more valid this assumption. The greater the number of proofs evaluated, the more statistically accurate the film thickness correlation becomes.

What problems can be caused by film thickness variation between proofs in a colorant file?

For Transparent Colorant Sets (without white), each proof is converted to K/S independently of any other proof. To determine a relationship of K/S to concentration we must assume that the only variable affecting a proof's color strength is the concentration of colorant present.

Film thickness variability can have the same result as colorant strength variability. If film thickness varies, K/S values will be attributed to concentration which are actually the result of BOTH concentration and film thickness combined.

For example, two proofs of rubine red at 40% and at 50% concentration are prepared. The 50% proof is 25% stronger than the 40% proof so long as they are proofed at equal film thickness. However, if the 50% concentration is proofed at 1.2 times the film thickness of the 40% concentration, the 50% proof appears 50% stronger (assuming transparency).

Reducing the 40% proof film by 20% is even worse; the 50% then appears 56% stronger.

Randomly varying film thickness across a Transparent Colorant Set (single constant), therefore has the same effect as randomly varying the concentrations. The system never gets an accurate description of the concentration which corresponds to each proof. The more opaque the Colorant Set, the less this effect. If every proof is opaque, film thickness is irrelevant (and an Opaque Set should be used).

Film thickness variation in a Translucent Colorant Set (with white) presents a different problem. Assuming that one can print a consistent film over black and white for each concentration, film thickness differences between concentrations have no effect. As long as corresponding over light and over dark prints are at the same film thickness, separate proofs can vary. The "important" print is the calibrating white.

The "standard" film thickness for a Translucent Colorant Set (with white) is determined by the calibrating white proof. All other colorants are calibrated "relative" to this proof. To change the unit film thickness, one needs only to change the white proof and re-calibrate the file. It is not necessary to re-proof the Set at a different film thickness.

The more opaque the ink film, the less important film thickness and substrate color/absorption variations become.

Bronzing

What is bronzing?

Bronzing is the term given to a surface effect which cause the perceived color or a sample to differ with the angle viewed. Some pigment particles are not completely surrounded by resin.

The sample may be generally over-pigmented, or particle-size distribution in the sample may be such that small particles "float" to the surface of the wetfilm, increasing the pigment concentration and violating the critical pigment-to-binder ratio, at the surface.

Bronzing is common in some pigments. Reflex blue or rubine red will bronze in relatively low concentrations, although any pigment will show the effect at high enough concentration.

Why is bronzing a problem?

The problem is because the instrumental analysis, using an integrating sphere, of bronzed color will not agree with visual assessment. If we view a bronzed sample at a single angle, the color we see might not be influenced by the bronzed surface. The sphere instrument illuminates the sample at all angles simultaneously, so that the bronzed color affects the instruments measurement more than our visual assessment. In other words a bronzed blue appears much more red, inside the integrating sphere than outside of it.

What problems will bronzing cause in a Colorant Set?

The amount of bronzing effect present on a proof seems to depend mostly on pigment concentration. Whether the bronzing is present at all pigment concentrations or if there exists some "threshold concentration" below which no bronzing occurs, depends on pigment chemistry, particle size distribution, resin/solvent solubility, etc..

In any case, the portrait of a bronzed colorant would generally include a specular value lower than the rest of the Colorant Set, and reflectance curves of higher pigment concentrations which are at some points higher than reflectance curves of lower concentrations. A K/S vs. concentration plot, at absorbing wavelengths of a bronzed colorant, would have a negative slope in the higher concentrations. This "negative K/S build" will be more pronounced at some wavelengths than others. Generally, the wavelength of maximum absorption for the lower concentrations, is considered the proper wavelength for this evaluation.

In Transparent Colorant Sets (without white), the system will not use concentrations lying on the "negative build" portion of the K/S vs. concentration plot. Attempts to match standards containing high concentrations of the bronzed pigment will fail, or result in metameric matches, as the system tries to reproduce the bronzed pigment with combinations of other colorants.

For Opaque and Translucent Colorant Sets (with white), bronzing is more difficult to diagnose. In addition to a lower than normal specular value, the bronzed colorants' wavelength of maximum absorption might be different for its mix with white than for its mix with black.

How is bronzing eliminated?

Overprint the bronzed proofs. The problem is caused by pigment particles which are not completely surrounded by resin or "wet". Adding more resin wets the dry pigment and removes the effect of bronzing, at least at the surface.

The exact nature of the resin to be used for overprinting is a matter of debate. Some suggest the most transparent, colorless resin available. Some suggest using the same resin in the bronzed proof. Theoretically, specular reflections should depend on the resin system and not the pigment. The bronzed proof does not have a smooth, resin surface but a surface more like sand-paper with pigment particles sticking through the resin film. To avoid trapping small air bubbles, and possible internal optical interfaces, using the same resin seems to be the best suggestion.

How can I match to a bronzed standard?

Wet the pigment causing the bronzing. Overprint with resin. If the samples cannot be treated in this manner, one may try an evaporating oil or water. However, one should not expect the best results from these methods. Specular excluded measurements (on a sphere instrument) agree more closely to visual assessment of bronze samples than specular included measurements but do not eliminate the problem.

Ink fan decks are notorious for bronzing. Overprinting an entire book and measuring that book only is a widely recommended practice. If one has available the same pigments as those in the bronzed proof, it is likely that if the overprinted colors match, the non-overprinted color will also match. If one does not have the same pigments available, it is unlikely that one would be able to reproduce the bronzed color anyway.

Matching with Metallic/Pearlescent Pigments

How can I make formulations with metallic or pearlescent pigments?

Generally, if one uses a single metallic or pearlescent grade in color matches, the colorant set preparation and formulation using these pigments is straightforward. If one uses a number of different colored metallic or pearlescent primaries, the following recommendations do not apply.

Metallic and pearlescent flake pigments in an ink film have similar effects on light. Like white pigments, they have relatively low absorption and relatively high scattering values. Unlike white pigments, the scattering they posses is highly directional. The color perceived from the sample depends very much on the angle at which the sample is viewed.

Those who work with metallic and pearlescent grade pigments frequently use the terms “face color” and “flop color” to describe this geometric phenomenon. The magnitude of this geometric effect is influenced by the size of the pigment flakes and their "flatness" (orientation) in the ink film. Different grades of aluminum, bronze, and pearl flakes are available and different printing processes impose different limits on the particle sizes which can be used.

To prepare a Translucent Colorant Set containing metallics or pearls, two methods are suggested, as follows:

1. Store the metal/pearl as an alternate white.

Proof a press-ready metal/pearl ink on a contrast ratio chart. Store the proof as a “white”, and use this white during formulation. A disadvantage of this method is that it seldom works well if the calibrating white is not also a similar metal or pearl pigment.

2. Store the metal/pearl as a calibrating white.

Prepare a press-ready metal/pearl ink and make mixes of metal/pearl and colorants. Store and calibrate the file normally. Use the metal as white in formulation. Once this file is built, one can add additional grades of flake pigment as alternate whites.

To prepare a Transparent Colorant Set containing metallics or pearls, the following is suggested:

1. Store the flake pigment as an extender. Prepare let-downs of each (press-ready) colorant in (press- ready) metal/pearl ink. Store a proof of the 100% press-ready metal/pearl as the calibrating substrate. In formulation, when the system calls for extender it will really be calling for the metal/pearl ink.

Gloss Compensation

Gloss Compensation is a proprietary technology incorporated in Datacolor color control software for pigment using industries. It offers Paint, Ink and Plastics users the ability to more accurately match, correct, and control color, even as the gloss of standards and products differ.

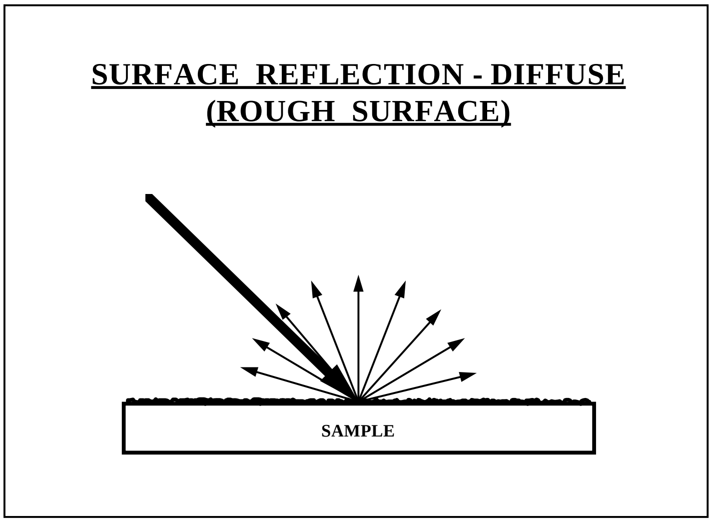
Color control systems employ spectrophotometers to measure light reflecting materials. These spectrophotometers usually use the Integrating Sphere-Specular Included optical geometry, though a few utilize 45/0, or Integrating Sphere-Specular Excluded**.** Each geometry has advantages and disadvantages, but none can fully determine both the color and gloss of a sample. Thus, color difference calculations and formulations can be less accurate than desired, particularly when sample and product gloss are different.

Datacolor Gloss Compensation systems more accurately “measure” samples by measuring both with Specular included and excluded. Then, by applying calibration and mathematical models, the following information is yielded:

- A Specular Included measurement.
- A calculated Gloss measurement.
- A calculated Visual (45/0) measurement.

By knowing all 3 functions, the Datacolor software can generate the best matches for, and most meaningful analysis of, all possible color and gloss combinations.

Surface Reflection



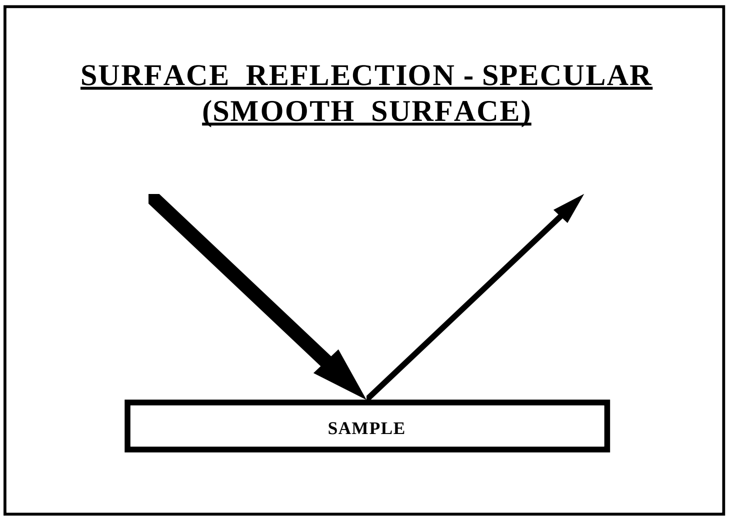
A matte sample - with a rough surface, the surface reflection occurs equally at all angles.

The reflection of light at the surface of a sample is the appearance effect that causes the gloss sensation. This surface reflection is also the effect that causes the failure of spectrophotometers to completely characterize both color and gloss.

In color applications, light travels through air and then is incident upon an object (sample).The index of refraction of air is 1.0, and the index of refraction of the sample might typically be about 1.5.

Whenever light travels from one medium to another (with different refraction indices), some light is reflected at the sample surface, thus never entering the sample. For most color applications, this surface reflection is about 4% of the incident light.

Spectrophotometer Optical Geometries



A high gloss sample - with a smooth surface, all surface reflection occurs at the Specular (mirror) angle.

Color spectrophotometers typically have either integrating sphere or 45/0 optical geometries.

Integrating sphere models either illuminate samples at all angles, and view them at an angle 8 degrees from the normal to the sample, or illuminate at the 8 degree angle, and view at all angles. These two measurement conditions, d/8 and 8/d respectively, are considered equivalent. The integrating sphere models usually can measure with either the Specular (gloss) included, or excluded.

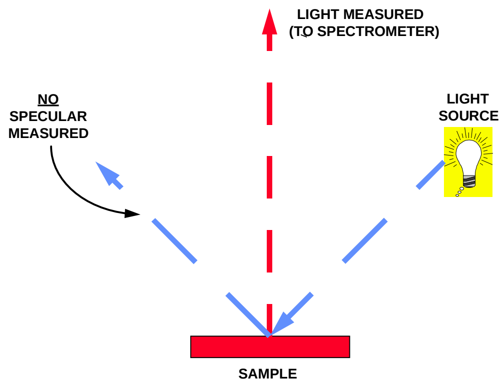
45/0 models measure the same as 0/45, excluding the Specular reflection. These spectrophotometers simulate typical industrial color viewing conditions.

Sample surface reflection is sensed differently by the d/8 Specular included, d/8 Specular excluded, and 45/0 optical geometries.

45/0 or 0/45

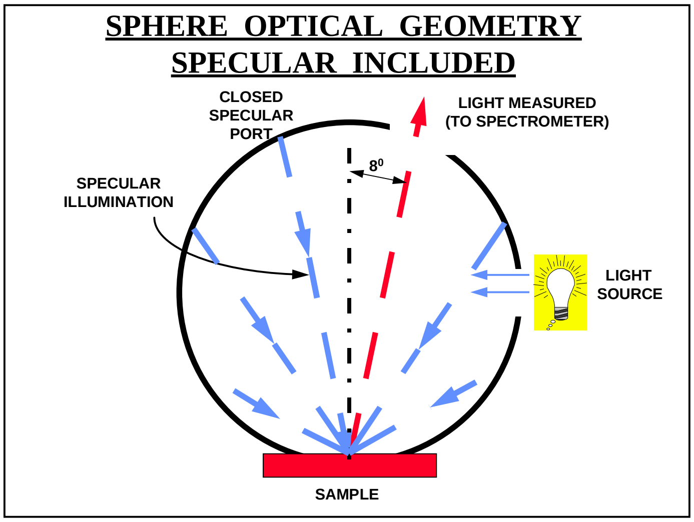
- Illuminates the sample at 45 degree angles.
- Specular surface reflection is excluded.
- Diffuse surface reflection is included.
- Poor repeatability, sensitive to sample surface variability and imperfections
- Simulates visual assessment.

45/0 OPTICAL GEOMETRY



Sphere-Specular Included

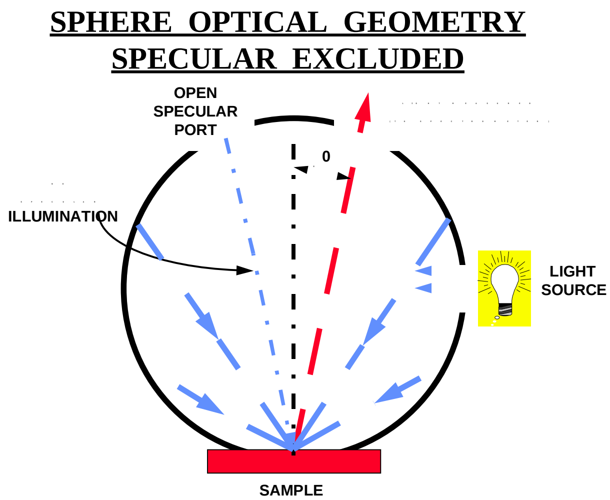
- Illuminates the sample equally at all angles.
- All the surface reflection is included.
- Good repeatability, not sensitive to sample surface variability and imperfections
- Does not sense sample gloss differences.
- Does not simulate visual assessment.



Sphere-Specular Excluded

- Illumination quality at all angles, except no illumination at near-Specular angles
- Specular surface reflection is excluded, though usually not completely
- Diffuse surface reflection is included.

Medium repeatability, somewhat sensitive to surface variability and imperfections



Gloss Compensation: why? and when?

Gloss Compensation is needed because the integrating sphere spectrophotometers used for most color work “see” the surface reflection of samples differently than how we view these samples. This can be described as follows:

1. Most color formulation and correction software programs utilize Sphere-Specular Component Included measurements. These measurements include the total amount of surface reflection, not being able to tell whether this surface reflection is all in one direction (gloss=100), diffuse (gloss=0), or at some gloss level in-between the extremes.

2. When making visual color evaluations, samples are usually viewed under conditions where Specular surface reflections are excluded. These optical conditions, standardized in light booths, are usually specified to be at 45/0 or 0/45 angles.

3. Spectrophotometer measurements made with 45/0 geometry will include that portion of the surface reflection that is reflected at the 0 degree angle. For typical paint, plastics, and ink high gloss samples, there will be little or no surface

reflection included. For typical highly diffuse samples, the spectrophotometer will measure about 4% reflection. These measurements agree with visual assessments, but are also sensitive to gloss variations, and often not very repeatable.

4. If two samples of the same gloss are being compared, for formulation or quality control purposes, then there is no need for Gloss Compensation. The Sphere-Specular Included measurements are ideal in these situations, as they are immune to sample surface variations.

5. For production color correction purposes, Sphere-Specular Included measurements are usually used, as the standard will have the same gloss as the final product. Even if the sampled batch has slightly different gloss than the final product, Sphere-Specular Included measurements will ignore production gloss variability, thus correcting the color properly. Gloss Compensation is not used for production color corrections, unless the standard and product have different gloss levels.
6. For formulation and quality control purposes, if the batch and standard have different gloss, then the Sphere-Specular Included measurements will not agree with (45/0) viewed assessment. Gloss Compensation is used in these cases to adjust the sphere measurements as if the were made in visual space.

Datacolor Gloss Compensation
Summary of Use Conditions

When To Use Gloss Compensation

Quality Control	Batch gloss different than gloss of standard
Formulation	Batch gloss different than gloss of standard
Production Correction	Product gloss different than gloss of standard

When To Not Use Gloss Compensation

Quality Control	Batch gloss the same as gloss of standard
Formulation	Batch gloss the same as gloss as standard
Production Correction	Product gloss the same as gloss of standard

An example: matte and glossy black

As an example of Gloss Compensation, a black plastic material was molded into a sample with glossy, semigloss, and matte surfaces. These samples were measured and color differences calculated for the following conditions:

- Sphere- Specular Included
- Visual (45/0) space, with Gloss Compensation

The samples were also evaluated using a light booth designed for industrial applications.

The results:

- The Sphere-Specular Included measurements resulted in CIELAB color differences of nearly zero, between the gloss, semigloss, and matte sample surfaces.

- The visual space data resulted in CIELAB color differences agreeing very well with visual assessment. The semigloss surface measured about 3.0 dE (lighter) than the glossy surface. The matte surface measured about 13.0 dE (lighter) than the gloss surface.

Comment:

Gloss Compensation has proven an effective tool for all colors where gloss is different between standard and batch samples. The greatest effect is for darker colors (like the black example).

--------------------------- CIELAB Difference ---------------------------	DF100 SAV/SCI D/8 D65 / 10 degree					
Std: BLACK-GLOSS						
	DE*	DL*	Da*	Db*	DC*	DH*
	-------	-------	-------	-------	-------	-------
BLACK-SEMIGLOSS	0.12	0.02	-0.03	0.11	-0.11	-0.04
BLACK-MATTE	0.21	-0.19	-0.07	0.06	-0.06	-0.07

Above:
*CIE L*a*b* data comparing black semigloss and matte samples, to glossy black. Sphere-Specular Included measurement data.*

Following:
*CIE L*a*b* data comparing black semigloss and matte samples, to glossy black. Gloss Compensation visual (45/0) space measurement data.*

--------------------------- CIELAB Difference ---------------------------	DF100 SAV/GLOSS D/8 D65 / 10 degree					
Std: BLACK-GLOSS Gloss 49.0 / 60^0						
	DE*	DL*	Da*	Db*	DC*	DH*
	-------	-------	-------	-------	-------	-------
BLACK-SEMIGLOSS Gloss 20.0 / 60^0	2.94	2.88	-0.09	0.55	-0.54	-0.13
BLACK-MATTE Gloss 4.1 / 60^0	12.82	12.73	-0.03	1.57	-1.56	-0.15

Datacolor Gloss Compensation
Summary of Measurements and Calculations

Measurements	Samples are measured in both Specular Included and Specular Excluded Modes
Gloss Calculation	Sample gloss is calculated for the gloss geometry as specified by the user
Data Stored	At user direction, the sample Specular included measurement data, and the calculated gloss value is stored

Visual Space (45/0) calculation	At user direction, a visual space (45/0) measurement is calculated and available for use in color and formulation applications

Spectrophotometers, Tips for Optimal Performance

Spectrophotometers designed specifically for the measurement of colored materials, are at the center of any modern color formulation, color production, or color quality control system. Although these color spectrophotometers are designed to measure samples both accurately and repeatably, they accomplish these measurements only within a range of applicable tolerances. Spectrophotometers are not perfect measuring devices, and how well they measure is often dependent upon factors under the control of the system operator.

The purpose of this document is to provide "tips" (recommendations) on how to better operate and control color spectrophotometers, so that their measurements are as accurate and repeatable as possible.

These tips are intended for those attempting to get the best possible measurement performance from their color measuring spectrophotometer(s). They do require an investment in time and care, and one must decide if implementing some (or all) of these tips is worth the effort.

These tips are suggested to those who are attempting to maximize the accuracy and repeatability of their color measurement operations. In many cases, failure to follow specific tips may have little or no effect on overall system performance, since correctable measurement errors may be much smaller than the color acceptability tolerances involved.

No matter how well the color spectrophotometer is maintained and operated, its performance is limited to its inherent capabilities. Therefore, it is best to:

- Purchase only from a reliable supplier with a history of producing quality instruments and satisfied customers.
- Purchase the model spectrophotometer that has the features and capabilities necessary to meet the needs of the specific application involved.

Summary of Color Spectrophotometer Tips

1. Maintain the spectrophotometer according to manufacturer recommendations, including periodic testing and preventative maintenance, by qualified service personnel.
2. Operate the spectrophotometer in a temperature-controlled, clean environment, and (if possible) leave it under power at all times.
3. Maintain the white and black calibration standards so that they are clean, and safe from potential damage.
4. Recalibrate more often, perhaps every 2 to 4 hours and immediately before important jobs, even if the manufacturer normally suggests that recalibration is necessary only every 8 (or more) hours.
5. Consider that almost all dyes and pigments change color as temperature changes. Measure samples at the same temperature each time, if possible.
6. For samples that are not opaque; prepare them by increasing sample thickness, so that they are opaque (or nearly so), unless one is intentionally measuring over white and/or black backgrounds.

7. For samples with directional surface orientation**;** measure them always at the same single orientation**,** or measure them at the same four (4) orientations (90 degrees apart) with data averaged.
8. For samples with inconsistent color and/or surface effects; measure them multiple times (moving the sample between reads to increase the effective area measured), with data averaged**.**
9. As practical, utilize the largest sample measuring area available (LAV, SAV, USAV), to achieve averaging over a larger sample area (see #10).
10. If possible**,** always measure standards and batches (of colors to be compared), using the same sample measuring area.
11. If possible**,** always measure standards and batches (of colors to be compared), using the same spectrophotometer, under the same conditions.

More about the recommended tips:

1. Qualified regular preventative maintenance will assure that the spectrophotometer's integrating sphere coating is within acceptable reflectance parameters, and that the instrument continues to operate within specification.
2. A constant temperature environment will eliminate measurement variability caused by thermal changes within the instrument. Therefore, it is best to maintain power to the spectrophotometer (to eliminate warm-up thermal drift), and to keep the room environment at nearly constant temperature**.** Maintaining a clean operating environment will extend the life of the sphere coating, and reduce the chance of long term drift caused by dirt accumulating in the instrument's optical components**.**
3. Maintain carefully the white and black standards**,** since the photometric scale (0 to 100%) of the spectrophotometer is calibrated to these standards. Handle and store the white tile so that it does not become soiled or scratched. If soiled, clean the tile using water (and if necessary a mild soap), drying with a clean non-abrasive, non-optically whitened paper towel or cloth. If dirt or dust enters the black trap, clean it using a compressed air flow.
4. Recalibrate more often because the photometric scale (0 to 100%) of any spectrophotometer may "drift" over time between calibrations, due to temperature, light source and/or photodetector factors. Any "drift error**"** is eliminated at calibration, and greatly reduced by recalibrating often.
5. The fact that pigments and dyes change their color properties as their **is** temperature changes, potentially a major source of errors in any color measurement operations. Almost all colorants (except white and black and some blues) change color as their temperature changes. The color changes can be significant, and are typically in the range of about 0.6 to 1.1 dE CIELAB for most high chroma colorants, for a 10 degree C temperature change. If production samples (batches) must be measured at a temperature different from that when the standard was measured, then (if possible) remeasure the standard at the new temperature.
6. Non-opaque samples such as textile substrates, most papers, and many printing ink substrates, usually must be measured as if they were opaque, to meet particular color application needs. In these cases, it is best to increase sample opacity by increasing sample thickness, so that the color measurement will not be influenced adversely by the "show-through" of a black (or white) background. Textile cloth can be folded multiple times, yarns and threads wound in multiple layers, and papers stacked, to meet the desired opaque (or most nearly so) requirement. If multiple sample folds result in sample "billowing" into the sphere, then it is best to limit the thickness, and use a white sample background.
7. Optically directional samples **(**such as corduroy fabric, calendared vinyl, and card wound yarns and threads), typically measure differently in Diffuse/8^0 spectrophotometers, as they are rotated in the sample port. The directional geometric properties of these samples can result in measurement errors, whenever the standard and batch are measured differently. The measurement errors can be virtually eliminated by always measuring with the same sample orientation, or by measuring the sample 4 times (at 90 degree intervals) and averaging the data.
8. Inconsistent (or irregular) samples can yield different measurements, depending upon what part of the sample is measured. This measurement variability can be virtually eliminated by measuring the sample multiple times and averaging the

results, moving the sample between measurements. This technique can also be successfully employed in cases where the sample may appear to be uniform, but may not be.

9. The largest viewing area available should generally be utilized, as it extends the measurement over a larger portion of the sample.

10. Use the same viewing area for measuring the standard, as will be used in measuring production batches. This technique is desirable since different viewing areas (even of the same spectrophotometer), will typically not measure exactly the same.

11. If possible, use the same spectrophotometer, under the same conditions, to measure any samples to be compared, since no two spectrophotometers agree exactly.

Performance Factors

Performance Factors are displayed for batch evaluation. they are an index of actual versus theoretical results in a batch having known colorant amounts.

A Performance Factor (PF) of 1.0 means that the Colorant is behaving at 100% strength.

A PF of .8 indicates that the colorant is behaving at 80% strength.

A PF of 1.25 indicates the colorant is behaving at 125% strength.

Contrast Ratio Specification

Contrast ratio specification (or Match to Contrast) allows the operator to optimize the pigment load for desired opacity in a formulation.

NOTE: A Contrast Ratio is a “measure of opacity”. This is expressed as a percentage of the “Y” value of a sample measured over the dark portion of the substrate divided by the “Y” value of a measurement over the light portion of the substrate. A Contrast Ratio of 100% is defined as complete hide (opaque).

Input Requirements

Before you can perform a Contrast Ratio match, you must create an “*Absolute*” master white sample. Since all other colorants in a set are calibrated relative to the master white, absolute data can be determined for each colorant in the file. By storing the single white absolute sample, you can get absolute data for the set; **absolute data is required to perform non-opaque matches.**

Follow these general guidelines to prepare the necessary master white sample.

1. Create a *Translucent* Colorant Set.

2. Define the transparent “Clear” material you will use to reduce colorant loading. This does not require a physical sample or measurement. It is used for the name and properties only.

3. Define the Substrate. When you prepare your absolutemaster white sample, it should be applied over a substrate with contrasting backgrounds. Black and white are most commonly used for the substrate to calculate contrast.

Input Requirements (cont)

4. Prepare the incomplete hide sample of the absolutemaster white. This could be achieved by one of the following methods:

- The sample, when applied at normal film thickness is naturally translucent. If the sample is opaque, do one of the following:

- Add clear until the white sample is translucent at normal film thickness. Be sure to record the amounts of clear until a Contrast Ratio of 90-95% is achieved

- If the film thickness of the sample can be accurately measured, reduce the film thickness until translucency is acheived. Be sure to enter the actual film thickness of the white sample when storing the white. This may differ from the *Nominal Film T hickness* entered when creating the Colorant Set.

5. After you store, measure and calibrate this absolute sample, absolute K&S data will be calculated for all other colorants you store in the Colorant Set. The other primary samples for the set may or may not be completely opaque. The software allows for both.

   Remember that the accuracy of the predicted Contrast Ratio in Match and Correct output is dependent on the accuracy of your Absolute data. If your data is suspect, you may want to re-verify and/or recalibrate your Absolute data.

What Happens in Match and Correct

You specify your desired Contrast Ratio and film thickness and the program will calculate a formula(s) with a colorant loading to meet that specification.

NOTE: If the program cannot produce a match at the requested film thickness, the film thickness will automatically be rescaled.

What is Smart Match ?

Smart Match uses historical matching data to improve “first shot” matches on new formulas.

The formulas stored routinely in the Color Library or the In-Process are its source of information.

To use Smart Match, the operator simply measures the color to be matched and specifies the other requirements in the Match program. Smart Match automatically locates similar colors in the Color Library and the In-Process file. For each possible combination of colorants, Smart Match finds the performance of a similar match prediction and applies this information to the new match.

Other methods attempt to account for individual colorant strength behavior in mixtures. Smart Match learns how the mixture behaves, so it can also account for hue shifts (distortions of reflectance curves). These shifts can be caused by off-spec shipments of colorants, or by special process conditions such as pigment co-grinding, variable substrate absorption, bronzing or heat.

Benefits of Smart Match

Smart Match uses the behavior of a similar mixture of ingredients, evaluated at 31 points of the spectrum, therefore:

Smart Match gives better initial match predictions

- Smart Match predicts the hue shifts as well as "apparent strength"
- Smart Match predictions are valid under any illuminant
- Smart Match uses previous formulas that have the same combination of ingredients

Smart Match information is easy to update and store

- Only one measurement I needed for each formula
- You can use any valid formula to update the color library (a "match to batch" is not required)

You can save formulas during routine operation directly from the correction screen

CIE 1976 L*a*b* (CIELAB)

The CIE 1976 L*a*b* color space is the most widely used method for measuring and ordering object color. It is routinely employed throughout the world by those controlling the color of textiles, inks, paints, plastics, paper, printed materials, and other objects. It is sometimes referred to as the CIELAB color difference metric.

The 1976 CIELAB color space is a mathematical transformation of the colorimetric system first published by the CIE in 1931. Both the 1931 and 1976 color spaces share the same fundamental principles, that:

- **Color** is a sensation resulting from the combination of a light, an object, and an observer.
- A **light source** illuminates an object.
- An **object** modifies light, and reflects (or transmits) it to an observer.
- An **observer** senses the reflected light.
- **Tristimulus values** are coordinates of color sensation, computed from the CIE (light, object, and observer) data.

The 1976 CIE L*a*b* system offers the following important advantages over the 1931 system:

- It is more **perceptually uniform**.
- It is based on the useful and accepted color describing theory of **opponent colors**.

The 1931 CIE system offered users the ability to <u>describe</u> and <u>order</u> colors. Through its system of color coordinates and associated diagrams, the CIE system also facilitated the <u>comparison</u> of colors. Graphical and numeric data were used to describe colors (and differences) using functions such as: **Y**, **x**, **y**, **purity**, and **dominant wavelength**.

Although the 1931 system proved useful, its practical application was limited as it did not express differences between colors in a uniform perceptual manner. The visual perceptions of differences (in lightness, purity, and dominant wavelength) were not usually consistent with the numeric information available from the system.

1976 CIE L*a*b* - perceptual uniformity

The 1976 CIELAB system improved on the 1931 system by organizing colors so that numeric differences between colors agreed consistently well with visual perceptions. This improvement facilitated and simplified the communication of color difference information between parties.

Opponent color coordinates

The method of describing (and ordering) colors by an **opponent-type** system has proven to be useful, and widely accepted. This approach follows the idea that somewhere between the eye and the brain, information from cone receptors in the eye get coded into **light-dark**, **red-green**, and **yellow-blue** signals. The concept follows the “opponent” basis that colors <u>cannot</u> be red and green at the same time, or yellow and blue at the same time. However, colors can be considered as combinations of red and yellow, red and blue, green and yellow, and green and blue.

In the CIE L*a*b* uniform color space, the color coordinates are:

L* - the **lightness** coordinate.

a* - the **red/green** coordinate, with +a* indicating red, and -a* indicating green.

b* - the **yellow/blue** coordinate, with +b* indicating yellow, and -b* indicating blue.

CIELAB - color system

The CIELAB color space can be visualized as a three dimensional space, where every color can be uniquely located. The location of any color in the space is determined by its color coordinates; **L*, a*,** and **b*.**

The **L*, a*, b*** color coordinates (of an object) are calculated as follows:

1. The **object** is measured by a spectrophotometer.
2. A **light source** (illuminant) is selected.
3. An **observer** (2^0 or 10^0) is selected.
4. **Tristimulus values** (X, Y, Z) are computed from the light-object-observer data.
5. **L*, a*,** and **b*** are transformed (computed) from the X, Y, Z data, using the CIE 1976 equations.

The L*, a*, and b* coordinate axis define the three dimensional CIE color space. Thus, if the L*, a*, and b* coordinates are known, then the color is not only described, but also located in the space.

Colors can also be described and located in CIELAB color space using an alternate method, that of specifying their L*, C*, and h* coordinates. In this method, the L* coordinates are the same as in L*a*b*, while the C* and h* coordinates are computed from the a* and b* coordinates. The same color is still in the same location in the color space, only there are two different ways to describe its position (L*a*b* or L*C*h*).

The **L*C*h*** color space is also three dimensional, however the color is located using cylindrical coordinates, as follows:

L* - the **lightness** coordinate, same as in L*a*b*.

C* - the **chroma** coordinate, the perpendicular distance from the lightness axis (more distance being more chroma).

h* - the **hue** angle, expressed in degrees, with 0^0 being a location on the +a* axis, then continuing to 90^0 for the +b* axis, 180^0 for -a*, 270^0 for -b*, and back to $360^0 = 0^0$.

Many CIE system users prefer the L*C*h* method of specifying a color, since the concept of hue, and chroma agrees well with visual experience.

CIE a*, b* chromaticity diagram

The a*,b* chromaticity diagram is a useful way to display the location of colors in the CIELAB color space. The colors can be located using either a* and b* coordinates, or C* and h* coordinates. In both cases, the L* coordinate is usually displayed separately, as a number.

Color differences in the CIELAB system

CIELAB color difference, between any two colors in CIE space, is the distance between the color locations. This distance can be expressed as **deltaE CIE L*a*b*,** where:

$$\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$$

ΔL* being the lightness difference.

Δa* being the red/green difference.

Δb* being the yellow/blue difference.

For those preferring to express differences in chroma and hue terminology, instead of da* and db*, the following terms are utilized:

ΔC* being the chroma difference.

Δh* being the hue angle difference.

ΔH* being the metric hue difference.

$$\Delta E^* = (\Delta L^{*2} + \Delta C^{*2} + \Delta H^{*2})^{1/2}$$

The ΔE* and ΔL* differences are the same, whether using L*a*b* or L*C*h*.

Color tolerances in the CIELAB system

The CIELAB system is often used to facilitate the quality control of colored products. In these cases, the color of the production sample is located in CIELAB space, and compared to the color standard for production. Color differences between the production sample and standard are computed, and then usually compared to the limits (tolerances) of customer acceptability for the colored product.

Acceptability tolerances are usually established between a supplier and his customer, based on historical experiences, and commercial factors. The CIELAB system is often utilized to help order and quantify the acceptability tolerances, for each customer and color combination.

When establishing acceptability tolerances, it is usually best to determine separate tolerances for dE*, dL*, da*, and db* (or dE*, dL*, dC*, and dh*). The separate tolerances allow the CIE system to be employed in acceptability applications, even as the customer acceptability criteria deviate from the uniform perceptibility of CIELAB color space.

Colorimetric Fundamentals

Light + Object + Observer

Colorimetry is defined as the **measurement of color**. The measurement of color allows colored objects to be described, ordered, and compared. These operations must be accomplished in a logical and repeatable manner, in order to allow successful color communications. And, successful color communications are essential if satisfactory industrial color control is to be accomplished.

Color is an aspect of visual perception that is not easy to define, and certainly not easy to measure. It is a sensation whereby a human observer can distinguish differences between two fields of view, where such differences are caused by spectral composition differences in the observed radiant energies. From this it can be concluded that color is:

- A **sensation**, dependent upon the observer.
- Only of interest if the **observer** can distinguish differences in sensations.
- Caused by spectral (wavelength-by-wavelength) energy compositions (distributions).

The spectral energy compositions that are sensed by the eye/brain system of the human observer, result from both:

- Sources of **light**, and
- **objects** that modify light.

Although various systems have been developed for the measurement and ordering of color, the most important system, by far, is the CIE system. First published in 1931, this colorimetric system is based on the principle that the color of an object is a combination of **light**, **object**, and **observer** properties. The CIE (Commission Internationale de l'Eclairage) is an international organization concerned with light and color, that continues to further methods and standards concerning these subjects.

1. Elements which cause the color stimulus

The CIE system is based on the premise that the stimulus for color is provided by the proper combination of a source of light, an object, and an observer. The sensation of an object's color is produced by the combination of:

- A **light source** - illuminating an object.
- An **object** - reflecting or transmitting light to an observer.
- An **observer** - sensing the reflected light.

The combination of these three is considered on a spectral (wavelength-by-wavelength) basis.

2. Light source

Electromagnetic energy exists as waves, which can be described by their wavelengths or frequencies. The wavelengths of these waves are distances, with 1 nanometer (nm) equal to 10^{-9} meters.

Humans can “see” electromagnetic energy over a range of wavelengths from about 400nm to 700nm.

This part of the electromagnetic spectrum is called the visible (or color) spectrum.

Light sources can be described by their relative energy outputs, wavelength-by-wavelength. These outputs are called relative spectral energy (or power) distributions. The color producing effects of light sources result from the relative amount of energy available, not the absolute amount of the energy.

Light sources are also sometimes described by their correlated color temperatures. The correlated color temperature of a source is the temperature of a black body radiator that is most similar to the source. A blackbody radiator is an ideal surface that absorbs all energy incident upon it, and reemits all this energy. The spectral output distribution of an incandescent (tungsten) lamp approximates a blackbody at the same temperature. Correlated color temperature is typically presented using the absolute centigrade scale, degrees Kelvin (^{0}K).

The CIE has published spectral output data for various illuminants, in order to facilitate and standardize colorimetric computations. These illuminants include:

- **D65** - daylight, color temperature 6500K.
- **A** - tungsten, color temperature 2856K.
- **F2** - fluorescent, cool white.
- **F11** - fluorescent, narrow band cool white.

CIE Illuminant spectral output data is used in the process of calculating the color of illuminated objects.

3. Optical characteristics of colored objects

The spectral distribution of light reflected from an object depends upon:

- The light **illuminating** the object; and
- how the object **modifies** the incident light.

For opaque objects, reflectance is determined by the following optical characteristics:

- **Surface reflection** - diffuse (rough surface), or directional (smooth surface) reflection.
- **Absorption** - light enters the object and does not emerge (on a wavelength-by wavelength basis), as it is converted to heat.
- **Scattering** - light enters the object and is deflected (on a wavelength-by-wavelength basis); and is then eventually absorbed, or exits the object.

The reflectance of an object is determined by a spectrophotometric measurement, with calibration relative to an ideal white, and perfect black. Spectral reflectance curves, graphical plots of the reflectance data, are often a useful way of presenting this information.

Reflectance data (of the object), is used in the process of calculating the color of the object.

4. Observer

The human eye/brain system senses color through three types of sensors (cones), located in the eye's retina. These cones are sensitive to light in three different wavelength bands, referred to as the L, M, and S bands. Processing of the cone signals, by the brain, eventually yields output sensations interpreted as red, green, and blue (and/or combinations and differences of these primary colors).

There are two CIE standard observers that can be used when computing CIE tristimulus values. They are as follows:

- **2^0 Observer (CIE 1931) - for small objects.**
- **10^0 Observer (CIE 1964) - for large objects.**

The color matching functions of these observers, with tabulated data wavelength-by-wavelength, are utilized in the tristimulus calculations.

Tristimulus Values

CIE tristimulus values **X**, **Y**, and **Z**, are coordinates of color sensation, and form the foundation of the CIE color space.

The CIE tristimulus values are calculated by the spectral integration (multiplication and addition) of the following data functions, on a wavelength-by-wavelength basis:

- A selected **CIE Illuminant (D65, A, F2, etc.).**
- An **object's** spectrophotometric measurement.
- A selected **CIE observer (2^0 or 10^0).**

The X, Y, and Z tristimulus values define particular colors. These values are utilized in the computation of **CIE L*a*b* coordinates** (where colors are described and ordered), and **CIE L*a*b* color differences** (where colors are compared.