A QUALITY MANAGER'S GUIDE TO ~~THE GALAXY~~ *Colour Measurement*

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Introduction

In the beginning, humans would eat the food they eat, wear the clothes they wear and use the items they would use without much regard to what they really looked like. Nowadays, the first indication of quality of a product begins with how it looks; is it the right size and shape? Does it look like what it is supposed to? Is it the right *colour*? If you go into a supermarket and buy washing powder, you would expect it to be white. If you opened the box and found it was yellow, chances are you wouldn't be using it at all and may be a bit peeved you spent your money on it.

Fast forward to the present day and you will find that there are these wonderful people called "Quality Managers" whose role in life is to make sure that things look how they should; that washing powder is as white as fresh snow or that tomato ketchup is that perfect shade of tomato-ey red that creates an artistic fusion of colour when lathered over chips (as well as being tasty, obviously). Their job is to be the scrutinisers of perfection; the Kings and Queens of quality; the… other metaphorical entity that indicates they are really into quality control. It is the duty of a Quality Manager to supervise the product that they are responsible for and make sure everyone can see the high quality that they aspire to.

The problem is that these Quality Managers normally end up with many, many problems that pile up on their desks. Some of these problems normally contain the words "colour" and "appearance" and "wrong" as well as some choice others and can be quite repetitive, so Quality Managers end up with a lot of headaches.

Now, we've been about a bit in the colour and appearance world and, using the knowledge and experience we have with regards to public perception of quality, we have come up with 9 reasons to measure colour. (There used to be 10 but we thought "common sense" was a little too obvious to require being written down as an official reason, but if you would like to include it, be my guest).

We also understand how humans see colour and how we can use really clever instruments called Colorimetric Spectrophotometers to quantify what we see. All this will also be explained in this reference guide.

We like Quality Managers and want to provide them with many solutions for their colour and appearance quality problems so we have used our knowledge to create this masterpiece. Hopefully it will prove useful but, if you are a pessimistic soul and don't believe that perfect colour and appearance quality can be achieved, you don't have to carry on reading. If you don't want to stop quality problems before they occur, pop this book into a drawer so it will be safe and ready for you when you need it. If you have a 100% flawless, perfected process then… can we come and visit to learn what magic you possess? No process in any industry is perfect so that would be pretty amazing!

That's the aim of this book: helping you to achieve the unachievable. Giving you the knowledge of colour and appearance to work out a way to make it work for you.

Oh, and I should also add, if you've got any questions about anything you read in this handy little book, we've popped some contact details at the end; feel free to use them. (Preferably for colour related questions only but you can always try and throw us off and ask an astronomy or baking question if you fancy it.)

Happy reading!

Stotto

9 Reasons to Measure Colour

01 To set a standard in stone as well as quantify it, just in case it will not stay colour stable as it ages.

02 To make sure each batch is consistent, preventing complaints and returns.

03 To grade samples by appearance objectively. The better looking the product, the more money people will pay.

04 Monitoring changes to your process speeds up detection of failing components.

05 To establish an official measurement to make sure it is proof that when it left the plant, it was on colour. This saves the blame game occurring and days of troubleshooting and re-working.

06 It serves as an objective method to make additive corrections.

07 It helps prevent shipping off-colour products by acceptance of an objective measurement before an item is shipped.

08 To monitor incoming raw materials. If these are consistent it will focus your efforts on the process and also gives your suppliers a target to work towards. Not having a goal will encourage a problem.

09 To quantify people's preference. People judge the quality of the product on the way the product looks first, then by the other senses. Make sure you get to grips with what customers actually want and what puts them off purchasing (or paying a higher price).

10 *The unofficial 10th reason which should not be quoted* - because it's common sense to measure colour.

An Introduction to Colour

Well if you've got this far then you should have found a good enough reason on the previous page that peaked your interest. That, or you're just killing time between meetings or trying to look busy. Either way, we're happy you're still here.

The thing is, if you don't really know what you are looking for and what problems changing colours can indicate then you are going to be a bit stumped when someone complains that the colour is wrong or it wasn't the same colour as last time. What's that phrase? Ah, that's it: Knowledge is Power! With the right knowledge and understanding, you have the power to monitor your processes and make the necessary changes needed to keep colour and appearance quality not only good, but consistent.

So, as I have said before, colour is a key indicator of product quality. Look at anything near you; it can be anything. Where are you reading this? At a desk? On the sofa? On the bus? I assume you're sitting down somewhere. Look at the material that makes up your seat and then the material that makes up the back rest. Do they match? Now take a look at another seat; do they match also? If you're reading this at a desk, does the colour of the top match the colour of the legs? Everything that has been manufactured or produced has been subjected to some level of quality control to make sure all parts of the product match each other where they are supposed to.

These next couple of pages will provide a brief look at what colour is, how we see colour and how we measure colour to give you some theory into how all of this works.

What is Colour?

Seems a bit of a silly question but do you actually know what colour is? We all know the names of different colours: red, green, yellow, blue etc. But what actually is colour?

Oxford English Dictionary [https://en.oxforddictionaries.com/definition/colour] defines colour as:

1. [mass noun] The property possessed by an object of producing different sensations on the eye as a result of the way it reflects or emits light.

AND

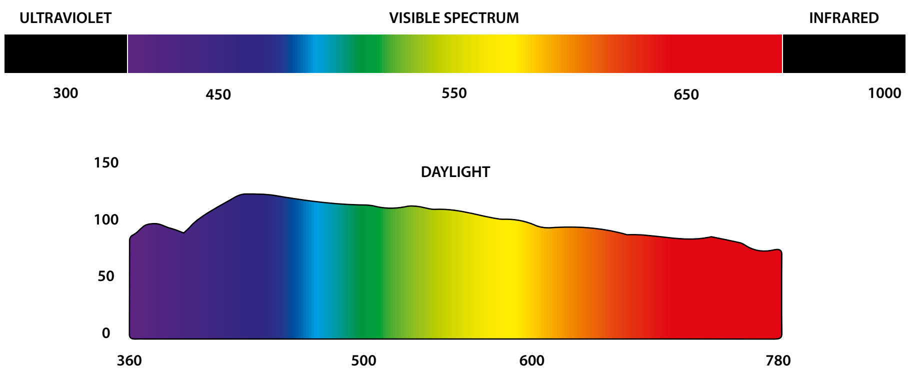
1.1. [count noun] One, or any mixture, of the constituents into which light can be separated in a spectrum or rainbow, sometimes including (loosely) black and white.

Both of these definitions describe colour in a way relevant to the task of colour analysis.

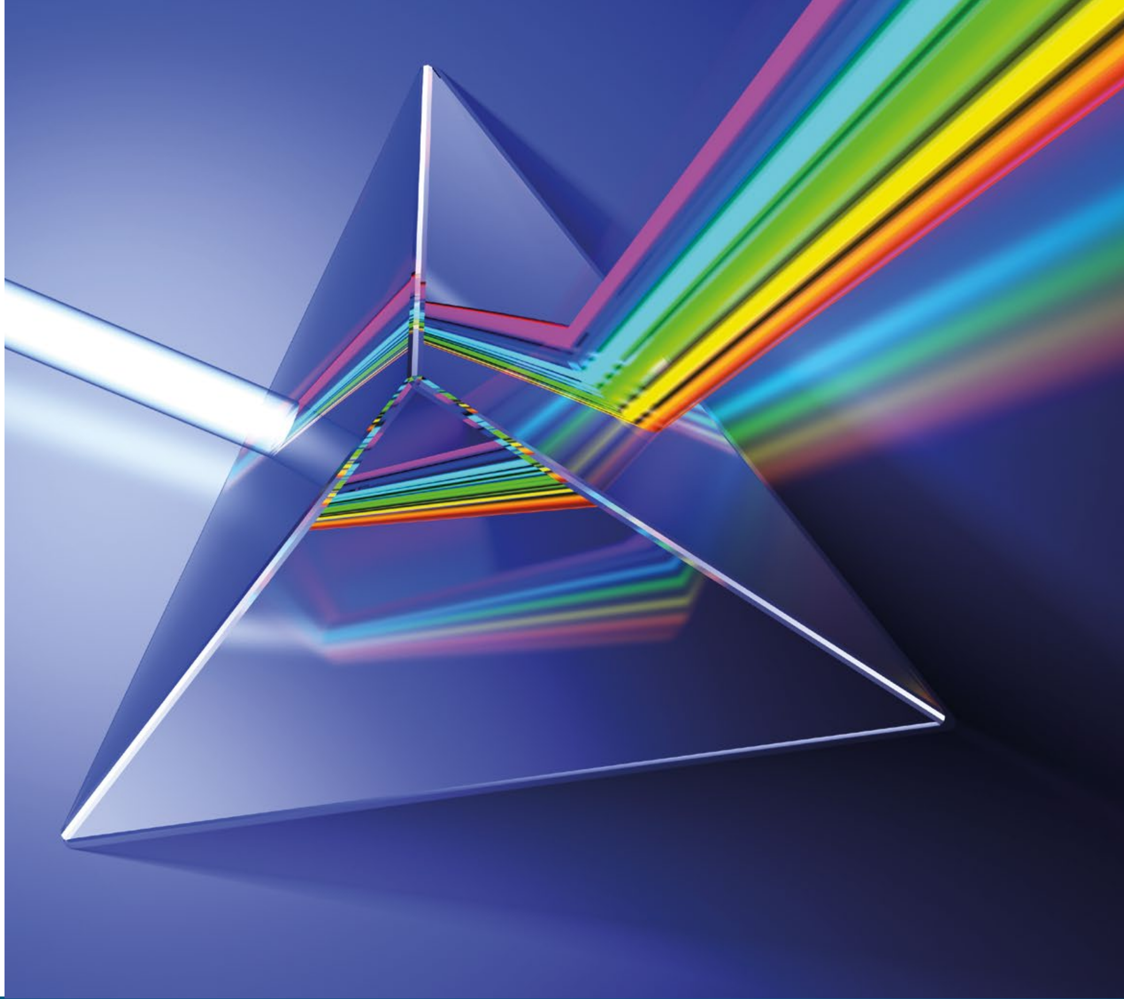
For Your Information...

- **Visible light is a small part of the electromagnetic spectrum.**
- **The wavelength of light is measured in nanometers, nm.**
- **The CIE wavelength range of the visible spectrum is 360 to 780nm.**
- **A plot of the relative energy of light at each wavelength creates a spectral power distribution curve quantifying the characteristics of the light source.**

The diagram below shows the spectral power distribution of sunlight.



A light source emits white light but when it is dispersed by a prism, all visible wavelengths can be seen.



How Do We See Colour?

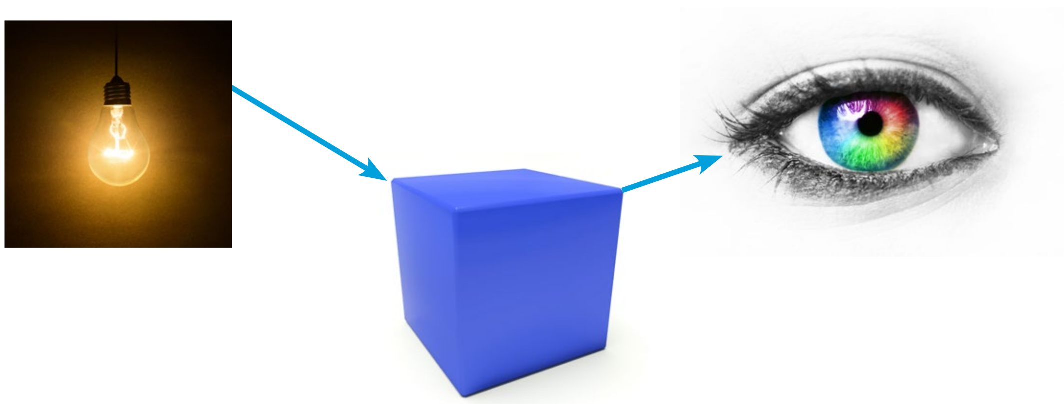
To see colour, you need 3 things:

Object

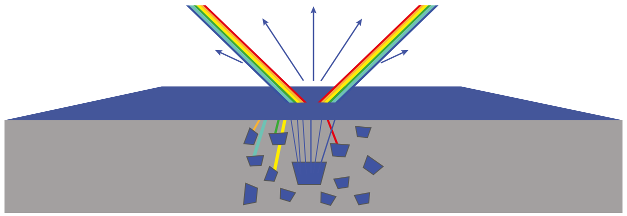
Light Source

Observer

Light from the light source shines onto an object and is reflected into our eyes.



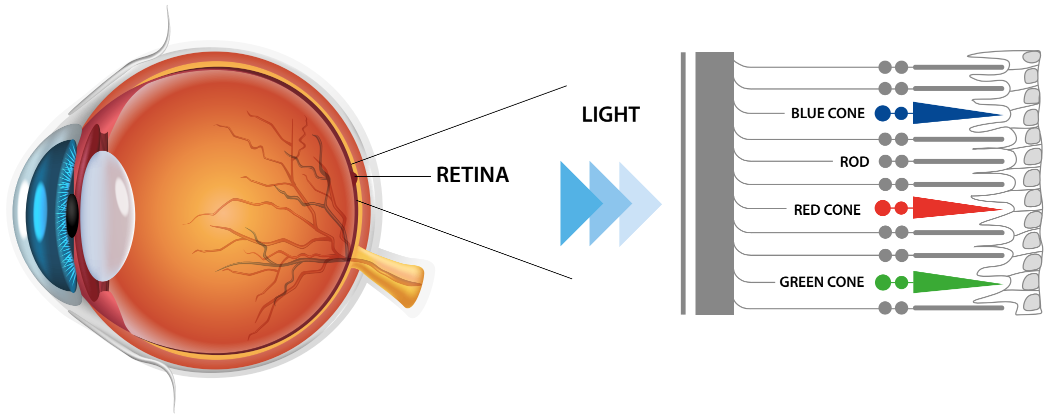
Certain colours are absorbed at different wavelengths and some reflected which is why objects appear to be different colours.



How Human Eyes See Colour

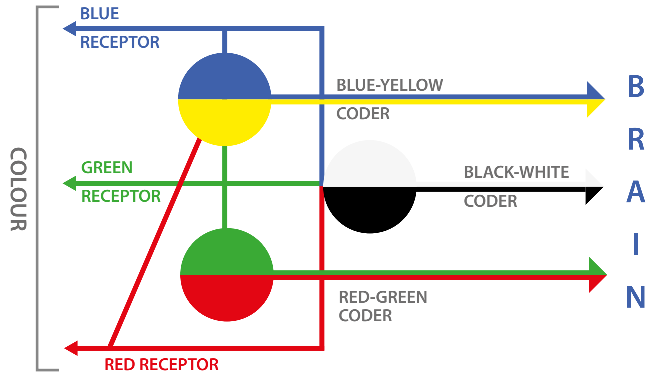
Human eyes are amazing things. For them to see colour, they have light sensitive receptors in the retina at the back of the eye. Some of these light sensitive receptors are called Cones. Cones contain colour-detecting molecules, normally red, green and blue. Each type of cone is sensitive to different wavelengths of visible light.

When you look at an object, the light shines on it and reflects some wavelengths back to your eye while some are absorbed by the object. The wavelengths that are reflected into your eye stimulate the cones in the eye and these send a message to your brain telling you what the colour is. Simple when you think about it.



Opponent Colour Theory

The Opponent Colour Theory states that red, green and blue cone responses are mixed into opponent coders as they move up the optic nerve to the brain.



Fancy testing this theory?

Focus your eyes on the black cross at the centre of the image below. Keep your eyes on it for about 20 - 30 seconds, then look at a white wall or sheet of paper.

Did you see the flag as red, white and blue? Awesome! This occurs because the green, black and yellow saturate the cone responses. When you look at something blank, your vision tries to re-balance so you see the colours as red, white and blue. And there you have it… Opponent Colour Theory!

How Do We Measure Colour?

To quantify colour, you need 4 things:

Sample

The **sample** would be a section of your product that requires quality analysis.

Illuminant

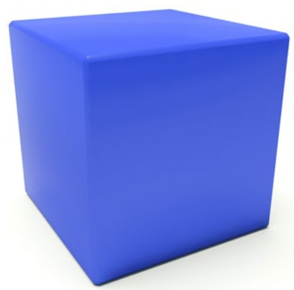
The **illuminant** can vary, for example daylight or fluorescent light etc, depending on the conditions the sample needs to be viewed under and is a table of numbers representing energy in relation to wavelength for the spectral characteristics of different light sources.

Observer Angle

The **observer** angle is either 2° or 10°. 10° is more commonly used as it gives a wider field of view for the data calculations.

Instrument

The **instrument** would be a colorimetric spectrophotometer that can give numerical data based on operator configured parameters.



Sample

D65 / 10

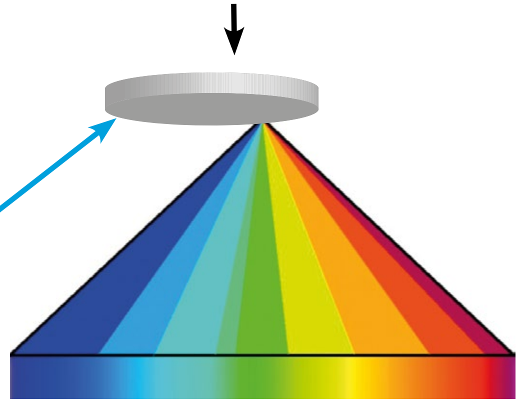
Illuminant / Observer

Instrument

How Do Colorimetric Spectrophotometers Work?

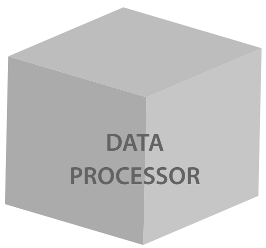
01.
A colorimetric spectrophotometer uses light to illuminate a sample.

02.
The reflected light from the sample is broken into its spectral components by a diffraction grating.



03.
The spectral components fall onto a diode array which measures the amount of light at each wavelength.

04.
The spectral data is sent to a data processor which uses illuminant and observer information to calculate CIE XYZ colour values.



Once you have your sample and decided on your illuminant and observer angle, the instrument can then calculate Tristimulus Values, also known as XYZ, for your sample.

As XYZ values are not easy to interpret, different colour scales have been developed to better relate how we perceive colour, simplify understanding, improve communication of colour and better represent uniform colour differences.

Colour Scale Examples

L,a,b Colour Scale

The L,a,b colour space is a 3-dimensional rectangular colour space. For each of the measurements taken, numerical data for the following will be shown:

L – Lightness axis – 0 is black, 100 is white.

a – Red to Green axis – positive values are red, negative values are green, 0 is neutral.

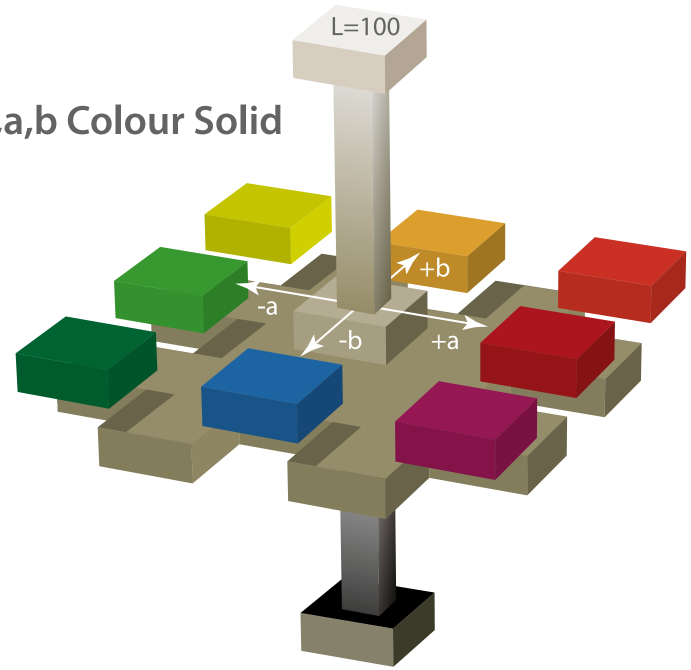
b – Yellow to Blue axis – positive values are yellow, negative values are blue, 0 is neutral.

There are 2 versions of the Lab Colour Scale: Hunter Lab and CIE Lab. These are calculated slightly differently so will give different results. They tend to be written as below:

Hunter Lab – L, a, b

CIE Lab – L*, a*, b*

L,a,b Colour Solid



Colour Scale Examples

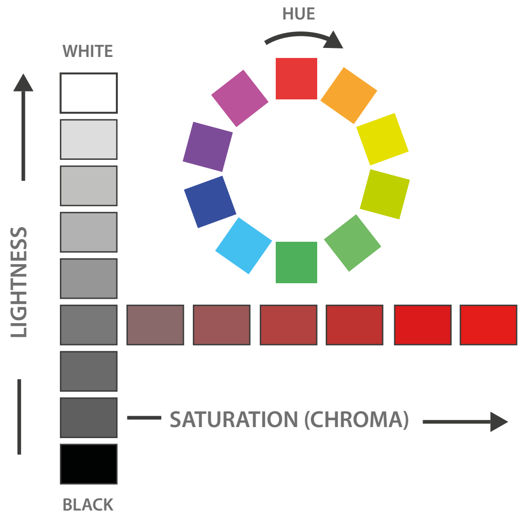
LCh Colour Scale

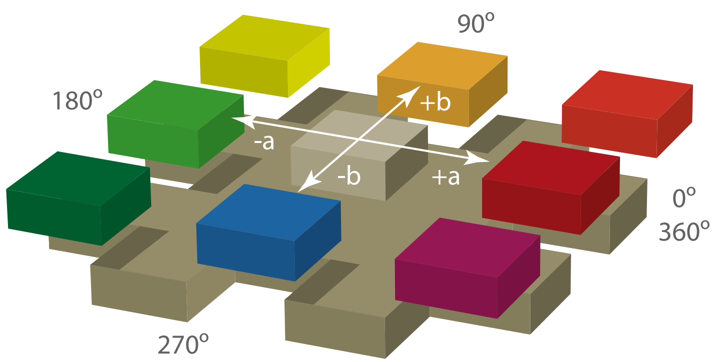
All colours are organised into 3 dimensions – Lightness, Chroma and Hue and are depicted in the LCh Colour Scale.

L – Lightness - 0 is black, 100 is white. (Equal to the L value in the Lab Colour Scale).

C – Chroma – shows the saturation of colour in the sample.

h – Hue – numerically depicted as a hue angle with 0° as red, 90° as yellow, 180° as green, 270° as blue and 360° back to red again. Please see the diagrams below for a more visual representation of the colour of angles.





How to Quantify Appearance

Quantifying appearance isn't simply saying "how blue is blue?" It's about providing traceable, numerical data that can not only back up your claims that your product is of a consistently good quality when it leaves your site but help you achieve that good quality. Quantifying appearance can tell you that your sample is too light or too dark, meaning it could be either over or under cooked. It can tell you your sample is too orange-red instead of purple-red or could be too hazy or have too many bubbles. Being able to quantify appearance is an extremely useful aid and can solve a lot of production problems.

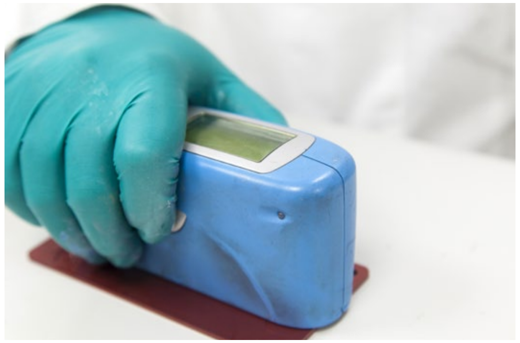
However...

As with most things, there is a right way and a wrong way to do it. Conveniently enough, there are also right tools for the job and wrong tools for the job. We vote that you use the right tools for the job. (Although we understand that you are your own person and you are perfectly at liberty to waste your money and your time if you choose, we just hope you won't.)

So, on the next couple of pages there is going to be a list of good tools and bad tools for quantifying appearance. What I will say though, is if you are not interested in spending a little bit of money to save you great reams of cash in the future then you may as well skip a page and head to page 17 for the wrong tools. As with anything, good equipment costs money, but not nearly as much as you will save… Just something to think about.

How to Quantify Appearance

Some of the right tools for the job



• Gloss Meter

A Gloss Meter does exactly what it says on the tin. It analyses samples to give gloss units, essentially saying how glossy the product is.

• Light booth

A light booth or lighting cabinet is a self-contained viewing area that controls the type of light a sample is viewed under. They are ideal for comparing what a product would look like under supermarket fluorescent lighting compared to normal daylight viewing, for example. They come with a variety of illuminates and are used to ensure that minimal ambient light affects visual quality checks. Very useful, I think you'll find.

• Spectrophotometer

Ah, the pièce de résistance: the spectrophotometer. These come in a wide variety of makes, models, sizes, shapes and functions. They can measure the transmitted and reflected colour of samples, also including haze and turbidity.

The wrong tools for quantifying colour

As we have yet to see or possess an eye that is capable of performing complex mathematical calculations in the few seconds that it views an object, or find multiple sets of eyes in a workplace that can view the colour of a sample exactly the same as each other, it goes without saying that eyes are no good at quantifying colour.

Yes, you may be able to look at two samples side by side and say with complete certainty that one is lighter than the other, but how do you translate that to a production line? Everyone's eyes are different; men are better at seeing small details and moving objects whereas women are better at seeing colour. Simply looking at a product is not a reliable enough method to approve products for shipping, particularly if they are going to be scrutinised by a paying customer.

• Old Colorimeters

Using instrumentation is a reliable method of quantifying colour and appearance, but only if the instrument is reliable itself and is built with CIE geometry, traceable to a CIE Standard. Otherwise, how would you know the results mean anything? Any instrumentation used should be checked by a qualified technician and traceable certification given to prove the instrument is measuring as it should be. Having a twenty year old colorimeter flash a light and give you some numbers doesn't automatically mean those numbers are correct.

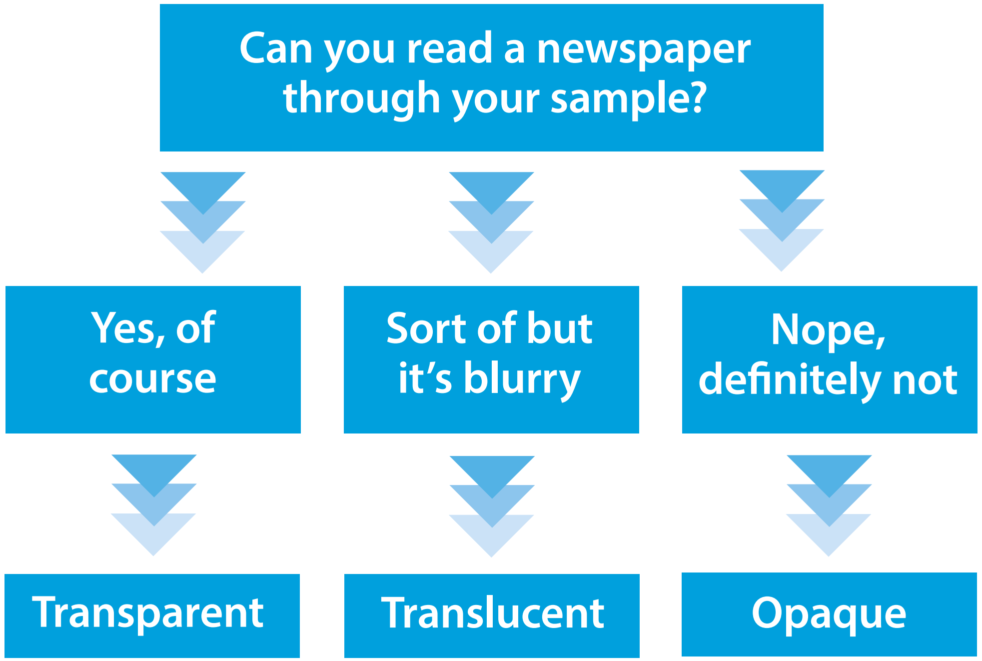
Common Applications for Colour and Appearance Measurement

How about we now get relevant to you and your product type? I know what you may be thinking: "It's too complicated to measure the colour of our sample," or "there's no way that you can get reliable, repeatable data from our sample."

The truth is that we can. Yes, we may need to take into consideration sample sizes and rack our brains for the best way to go about it but for the most part, we have already done all the thinking for you! (We've been doing this for a while, remember?)

On the next few pages are some different sample types and elements to think of when considering colour and appearance analysis. Take particular note of the sample type that best suits you.

First thing's first, however. The following pages will look at opaque, transparent and translucent samples. I'm sure you know the differences between them but have a quick gander over the diagram below just in case you're not 100% sure.



Opaque Samples

When we look at measuring the colour of opaque samples, we are looking at the reflected colour. This could be the reflected colour of plaques, liquids, pellets, powders and any other sample type that you can think of.

The method for measuring the colour of opaque samples remains the same for all sample types but the sample handling procedure differs. For example, if measuring the colour of a plaque, you could just present that for measurement. If measuring the colour of an opaque liquid, it would need to be held in a glass cell or cup of some kind.

Pellets and powders would also be placed in a glass sample cup that allows for accurate measurements without causing damage to the machine.

Measuring samples are actually quite easy to do; it's what to do with the data that is the tricky bit.

Translucent Samples

When we look at measuring the colour of translucent samples, we would, more often than not, look at the reflected colour. This is because, in a lot of cases, not enough light can pass through the sample for the transmitted colour data to be of any real use or relevance. For some samples though, this does depend on the sample size.

If we consider a liquid sample, we need to think what results would be more relevant to us. Are we wanting to measure the transmitted colour of the sample, as in the colour you see when you look through it?. Or are we interested in the reflected colour, such as when it is in a bottle on a supermarket shelf?.

For liquid measurement, there are different sample holding devices that can help with your measurements but you really need to know what you are wanting to measure. Have a look at the picture below; do you see the differences in colour depending on the sample cell's pathlength?

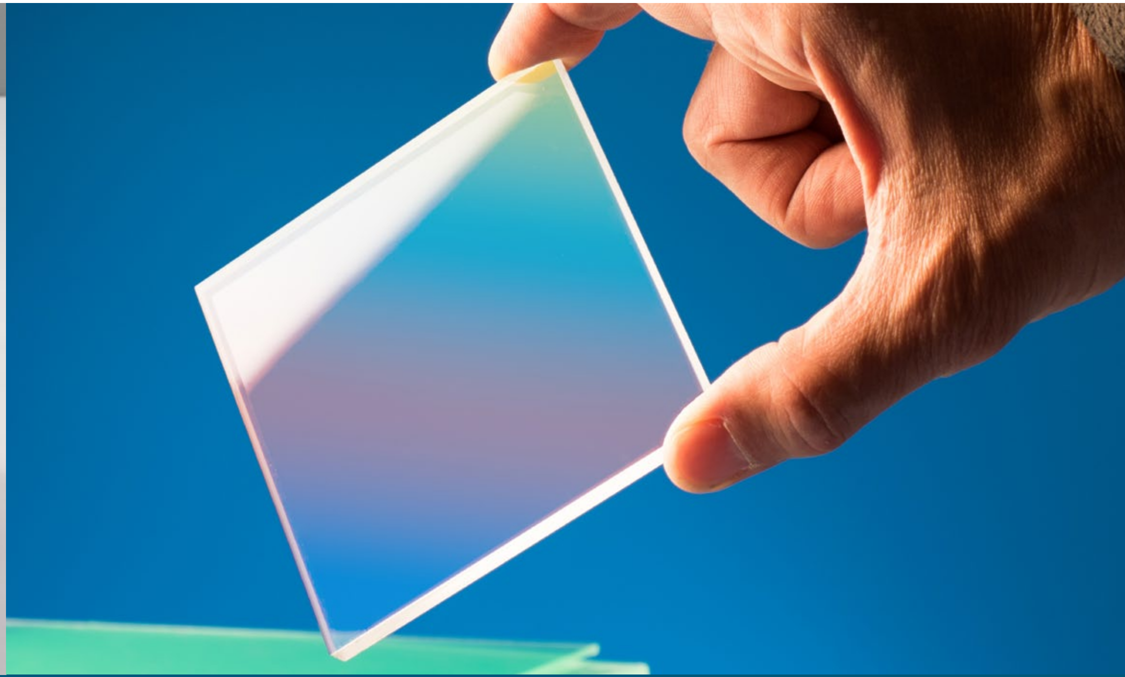
The transmitted colour would be good for the first cell but by the time you get to the third and largest cell, not much light would be able to pass through so you would get very low Lightness values. If this is relevant to you then fine, but in this case you may want to consider looking into the reflected colour.

Transparent Samples

When we look at measuring the colour of transparent samples, we are normally looking at the transmitted colour, particularly if the sample is completely see-through as there is nothing for the light to reflect off. In some applications, however, we may need to measure the reflected colour as well but this depends on the sample itself and the reason for measuring colour.

When measuring the transmitted colour of a sample, we can also look at its appearance, by way of quantifying haze or turbidity.

If the colour of your product can be affected by the amount of bubbles or the percentage of haze present, you will want to monitor this. If the quality of the sample can decrease with the increase of haze, then monitoring haze levels can indicate an issue with the production process, possibly allowing for changes to be made to rectify the haze problem.



How to Set a Colour Specification for Suppliers & Consumers (Ideally without scaring them)

Do you like your supplier? Good, we're glad you said that. If you hadn't it probably wouldn't be worth reading this section as we're sure you wouldn't be bothered about whether or not you scare your supplier. In all probability you'd probably find it entertaining but we are here to say no, don't do that. Be nice to your supplier and they will make your life easier in the long run. And we will assume you like your Consumers or Customers as, without them, you couldn't sell your product. That makes this section very important.

What we believe is a good idea is for everybody to work from the same book. If you and your suppliers have the same procedure, instrumentation and sample handling accessories, you can be sure that communication regarding the colour and appearance of the product will be more efficient. The way of communicating your requirements, including tolerances and expectations, comes in the form of a colour specification.

A colour specification is a document specific to a particular product and contains the following details, relevant to that product:

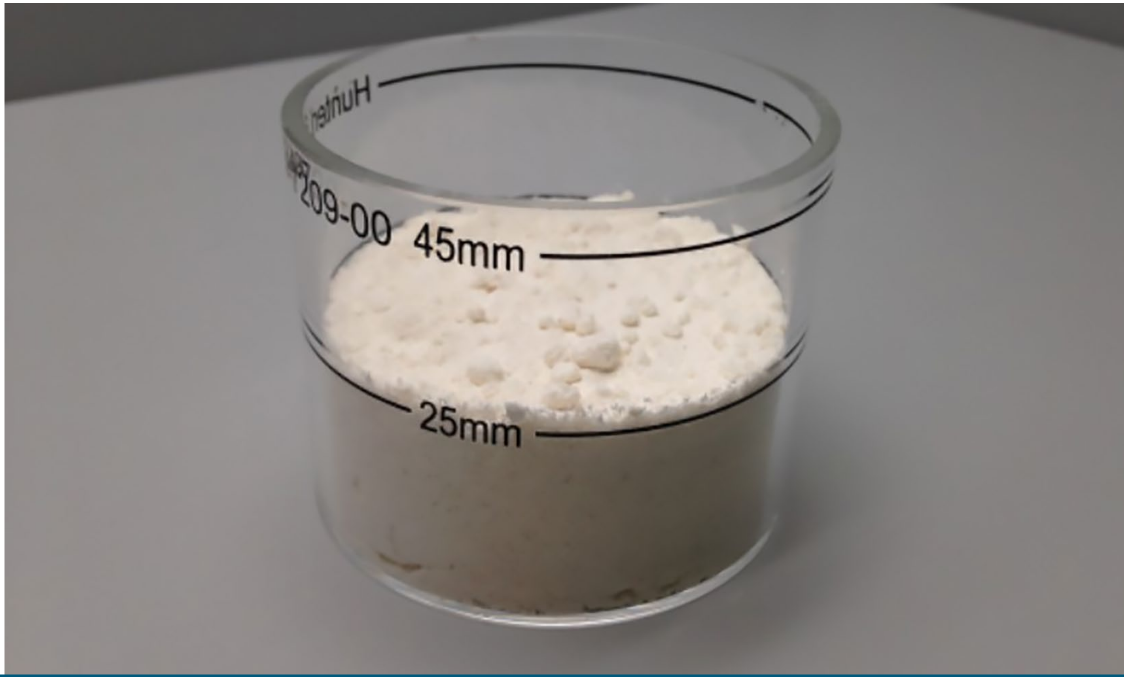
- Sample preparation
- Amount of measurements (average, if needed)
- Geometry
- Mode
- Illuminant
- Observer
- Colour Scale/s and Indices
- Tolerances

Yes, it's a lot of information needed about one sample measurement but it reduces the risk of any errors being made and ensures that if your supplier says the product is good, you can confirm it.

Sample Preparation

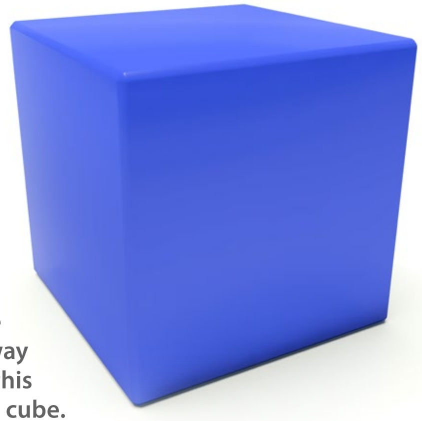
Preparing a sample for measurement should be done as consistently as possible from sample to sample. You should aim for the same sample size and measure the same area/s on the sample as a minimum. If you are comparing a sample to the rest of the batch, consistency is key otherwise you may find issues with the sample that might not be relevant or even there.

If we look at the image below, you will see on the sample cup there are marked measurement lines to ensure the user fills the sample cup with the same amount of sample each time. This is particularly important if measuring a liquid sample as the amount of light that may pass through the sample will increase with the less amount of sample used.



Amount of Measurements

For some samples, the amount of times you take a measurement and average it can have an effect on the results you are given. For a completely uniform surface, one measurement should suffice. For example, the material that makes up this cube is smooth and uniform all of the way around. If you are wanting to check that this cube is the same colour as the next cube made, you could get away with taking one measurement of this cube and comparing it to the next cube.



If you are wanting to make sure all of the sides of the cube are the same, you could take one measurement of each side and compare them. This should be nice and easy as the surface is flat and uniform so taking measurements at the same spot on each face of the cube would more than likely give consistently reliable results.

For more non-uniform samples, an average should be taken. This is to ensure that the measurements given are a better representation of the colour and appearance of the sample and do not focus solely on one part.

If you look at these powders, you will see that there are small particles as well as larger particles. These larger particles tend to cast a bit of a shadow which may be picked up during measurements. By averaging across the entire sample, you can ensure a more accurate set of results.

For extremely non-uniform samples such as crisps or snack foods, taking average measurements of singular crisps is time-consuming, irrelevant and will tell you nothing of real value. (Remember the idea is to make life easier for you.)

In applications such as these, continuous on-line measurements could be taken. This would take average measurements of the entire batch which would then allow for process alterations to be made if required. For example, if the colour of the batch measured was coming out a bit too dark then the operators would know that they are being over-cooked and can rectify the problem in a quick and efficient manner. If measuring singular crisps, it would be hours before it was noted that there was a definite problem and by that time, an awful lot of crisps would have gone through.

The amount of measurements depends entirely on your product, process and goals for colour measurement. Hopefully this has given you an idea of when you should be taking colour and appearance measurements so they can be beneficial and not simply a waste of time and money.

Geometry

Are you looking for data that tells you only what the colour is? Or data that tells you the colour in relation to how the human eye sees it? Not too sure? It's all to do with surface texture and the effect that it has on the perception of colour.

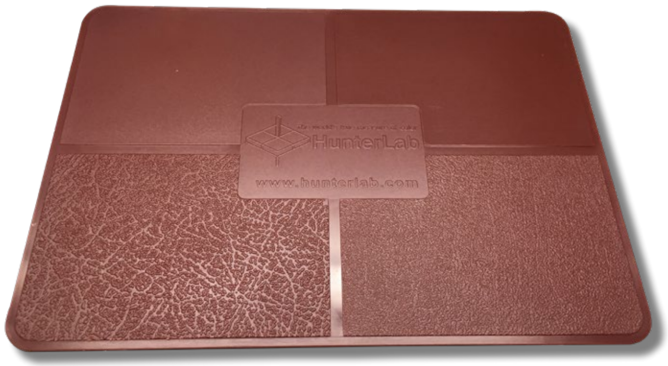
Take a look at the image below. This is a texture board with Glossy, Matte and Rough textured sections. They range from a dark red to a paler red colour which is quite clear to see.

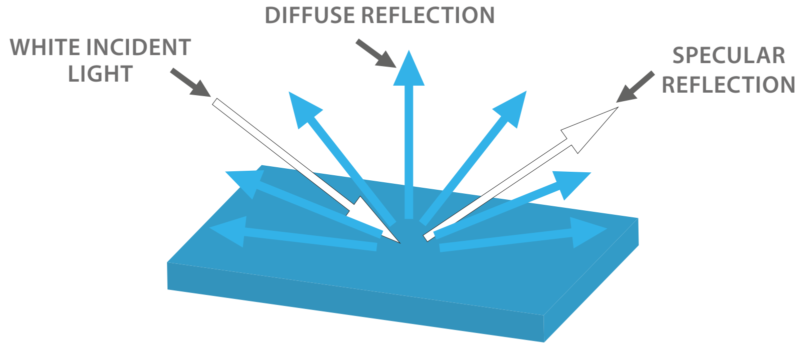
What if I told you they were actually all the exact same colour? I know, mind=blown! In all seriousness, they appear to be different colours because of how the light is reflected off the surface.

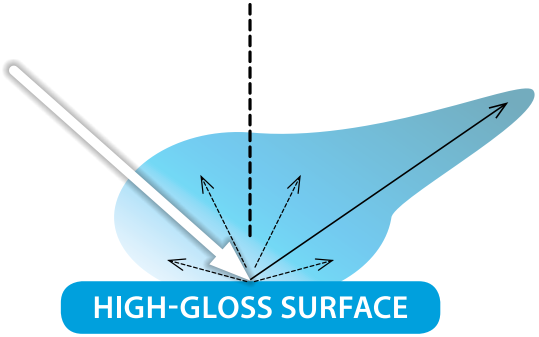
When light hits a surface, you get specular reflection which is the gloss or "shininess" and is reflected at an angle equal but opposite to the incident light. You also get diffuse reflection which contains the reflected colour of the surface.

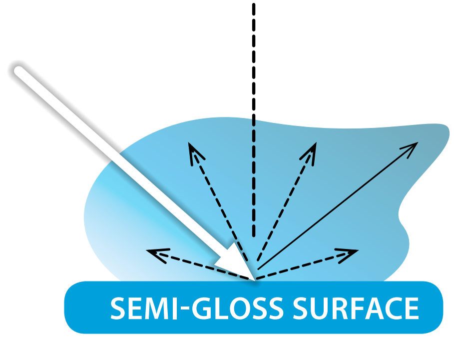
A more textured surface allows for more scattering of light which affects the colour and appearance. On a surface with more texture, the specular reflectance is scattered and mixes with the diffuse reflection, making the colour appear to be lighter and less saturated.

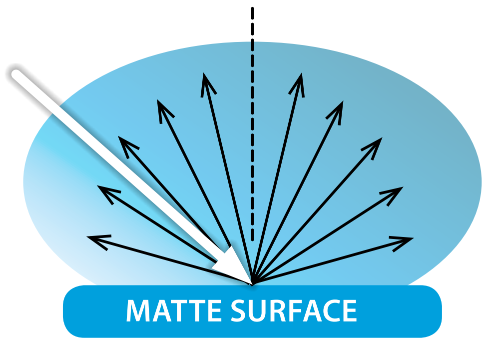
The diagrams to the right illustrate the amount of specular reflectance scattered over a variety of surface texture types.











Geometry

There are four main CIE geometries for colorimetric spectrophotometers:

- Diffuse 0°/8° Sphere, specular reflectance included
- Diffuse 0°/8° Sphere, specular reflectance excluded
- Directional 45°/0° (specular excluded)
- Directional 0°/45° (specular excluded)

If we want to measure just the colour of the sample, negating any effects caused by surface texture then we would use Diffuse geometry. Instruments capable of this use a sphere and provide diffuse spherical illumination, meaning that any surface texture is, for lack of a better word, ignored.

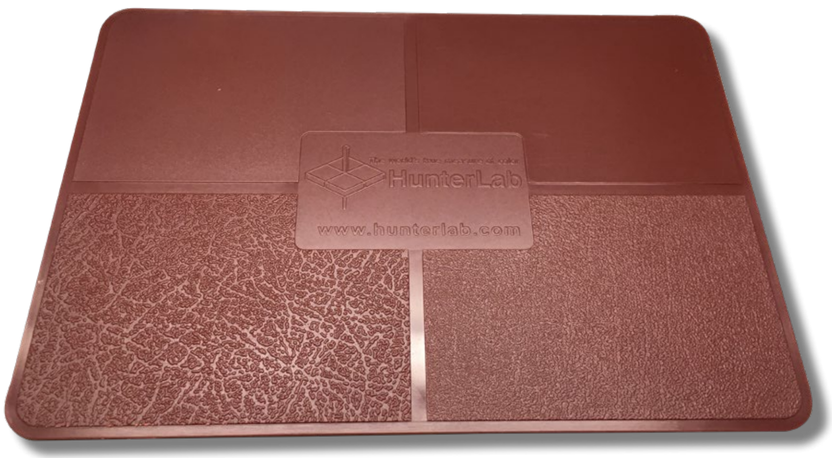
For measuring the colour of a sample how the human eye would see it, you need a geometry that takes into account the specular reflectance component, so we would use directional geometry. This would pick up the differences in colour that we can see by looking at the sample, rather than telling us the actual colour.

Let's look back at the texture board from earlier and pay particular attention to the glossy, rough and matte sections in terms of Lightness (or L values from the L,a,b Colour Scale).

If we were to use diffuse geometry, we would find that the L value for all sections would be very close as the specular reflection would be negated.

If we were to use directional geometry, we would find that the glossy section would have the lowest L value, followed by the rough and then the matte section with the highest L value.

So, now we've straightened that out, do you know how you want to measure colour yet?



Mode

The mode of an instrument used for colour and appearance analysis takes into account the port or viewing area size, as well as geometry.

Have a quick look at this image:

You'll notice the difference between each of the port sizes. On this particular instrument, the viewing area sizes range from 19mm up to 64mm.

It goes without saying that you need to keep the port size the same for every sample otherwise your results would likely be different. This means you are going to have to be super organised and make sure that the sample size available remains the same so you can use the same port. It's no good starting with a sample size large enough for the 25mm port plate but then find that you can't keep replicating that sample size so need to go smaller. That just sets you up for a few more headaches and we're trying to reduce those!

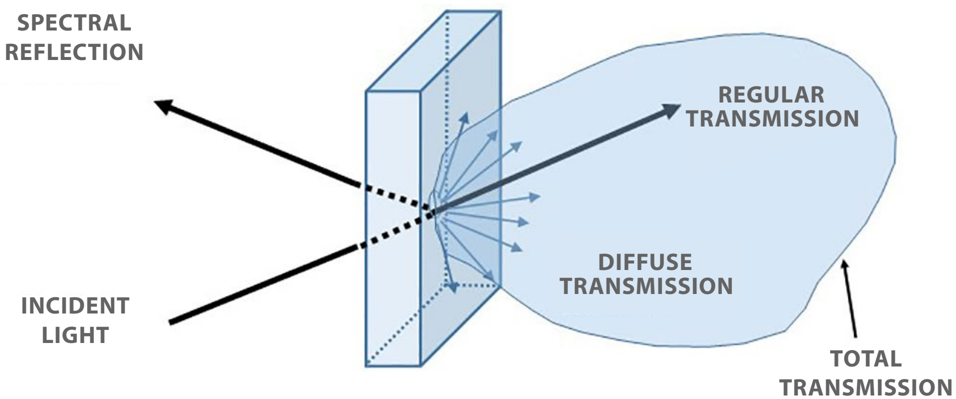
Mode

When measuring transmitted colour, we need to choose between either Total Transmission or Regular Transmission.

Colour is seen primarily in Regular Transmission as the light shines directly through the sample.

Diffuse transmission is caused by surface texture and scattering of light. This also contains colour.

Total Transmission is a combination of both Regular and Diffuse Transmission.



Illuminant

The difference between a light source and an illuminant is very simple. A light source is, not surprisingly, a physical source of light. An illuminant (or CIE illuminant) is a table of numbers representing energy in relation to wavelength for the spectral characteristics of different light sources.

As stated earlier on in this amazing little book, there are lots of different types of illuminants representing different light sources. Some of them are as follows:

- D65 - Natural Daylight
- F - Fluorescent Light
- C - Average Daylight
- A - Tungsten Halogen

A spectrophotometer can use the corresponding spectral data for these illuminants to give you colour and appearance information based on how it would look when viewed under that specific light source. As you can imagine, the results you get would differ depending on what illuminant is used. Another good reason to keep your method consistent and well-communicated between supplier, processor and manufacturer.

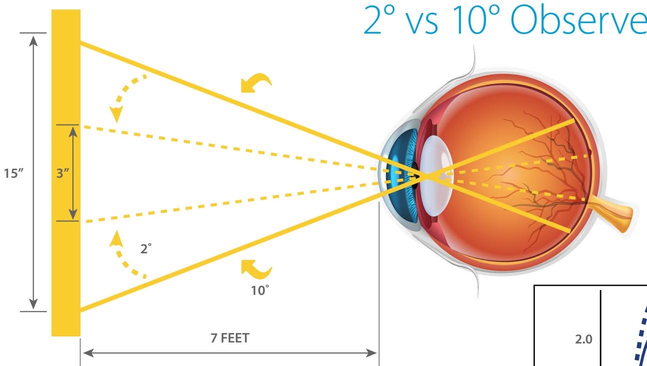
Observer

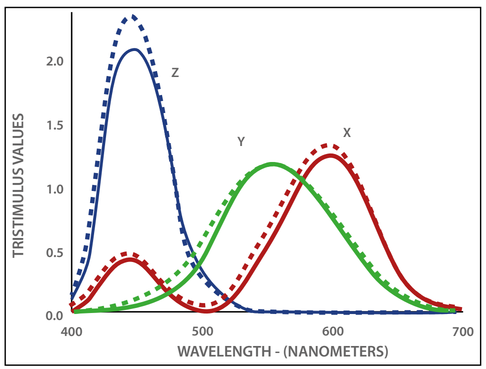
Many years ago, experiments were conducted to measure the human eye's ability to see colour. This involved a 2° field of view to match primary coloured light to a test light. The results from this experiment granted the scientific boffins the $\bar{x}$, $\bar{y}$ and $\bar{z}$ functions to quantify the red, green and blue cone sensitivity of the average human observer. This experiment enabled the formation of the CIE 1931 2° Standard Observer.

However, as with everything discovered, new knowledge and improvements can be made and when scientists discovered a little bit more information about the human eye, they re-did the experiment with a wider field of view. This brought about the creation of the CIE 1964 10° Standard Observer which is now more commonly recommended.

As these two observer angles use different size fields of view, they will give different results when used in colour calculations. Therefore, make sure both you and your supplier know which observer angle you are using and stick to it to prevent unnecessary problems.

2° vs 10° Observer





Colour Scales / Indices

As mentioned earlier in this booklet, there are many different colour scales and indices that you can use to give you relevant colour and appearance analysis data. All of these utilise the illuminant, observer and reflected or transmitted spectral data for samples in their calculations. It is important to make sure you use the correct colour scale/s for your application and ensure that anyone involved in the testing of the product all work to the same method.

This is particularly important when it comes to the two Lab Colour Scales; CIE and Hunter. Take a look at the differences in the calculations below:

• Hunter L, a, b

$$L = 100(Y/Y_n)1/2$$

$$a = \frac{Ka\,(X/X_n - Y/Y_n)}{(Y/Y_n)^{1/2}}$$

$$b = \frac{Kb\,(Y/Y_n - Z/Z_n)}{(Y/Y_n)^{1/2}}$$

• CIE L*, a*, b*

$$L^* = 116(Y/Y_n)^{1/3} - 16$$

$$a^* = 500\,[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}]$$

$$b^* = 200\,[(Y/Y^n)^{1/3} - (Z/Z_n)^{1/3}]$$

As you can see, they are calculated with some important differences. Miscommunication of the colour scale used can cause a quality issue, particularly if trying to match a sample measured with one colour scale to the other. This can result in unnecessary changes being made to the product, costing time and money and causing a lot of those headaches we mentioned earlier.

Tolerances

Tolerances are really helpful. It may take a bit of work to get them to a reliable point but once they are set, it makes quality control so much easier and can give operators a Pass or Fail notification for a product, depending on the tolerances set.

Essentially, by setting tolerances, the instrument is able to take all subjectivity out of quality analysis. Before, products were subject to visual scrutiny before being approved but with a spectrophotometer or similar, it acts as your eyes (but a lot more accurate and reliable) and can tell you with certainty if a product is good or bad. With its numerical data, it can tell you how far out of tolerance the samples are so you know how to resolve the issue.

To set tolerances for a product, you first have to decide that you know what a good version of the product looks like and what a bad version of the product looks like. (Yes, you can use your eyes for this.) This will help you set numerical values for your tolerances and be your confirmation that they are correct in the beginning.

You will then need to decide what physical characteristic causes your sample to be deemed of a poorer quality; is it how dark it is? Does the colour change? Or are you interested in the overall difference in appearance? You need to take a lot of measurements of good samples and note the limits of the characteristics that you want. For example, if Lightness is an issue, you may have a range of 79 to 82 on the L value for the good samples but as soon as it goes above or below this, it is noticeably of poorer quality. Therefore you can set tolerance limits and there you have it; a pass or fail on the lightness tolerance.

Rinse and repeat for any other colour scale or index and you're laughing.

Putting it into Practice

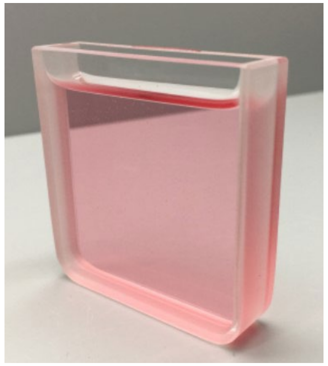
Example 1

Now you have been introduced to the theory of colour and appearance analysis, I think it's a good time to give you an example of how this would work in a realistic setting so you will need to use your imagination.

For this example, you are the manufacturers of a fruity beverage, the appearance of which is as seen in the image to the right.

The main issues that have been found with this product is that it can appear hazy and the colour can appear more "orange" than what is shown.

Issues such as these can call into question the quality of the ingredients and the efficiency of the manufacturing process.



To start with, we will work our way through the Supplier Specification to make sure we tick all of the boxes.

01. Sample Preparation

As the sample is a liquid and we are interested in the colour and the haze of the sample, it should be placed in a glass sample cell with a 10mm pathlength. This would allow for the measurement of transmitted colour and haze.

02. Amount of measurements

As this is a product that is produced on a large scale, we would be taking measurements at periodic points during batch production. This regular testing allows us to take singular measurements of samples but still achieve a good average across the batch.

03. Geometry

As we are measuring the transmitted colour, we will need to use a Diffuse 0°/8° sphere instrument.

04. Mode

For this application, we need to choose between Total and Regular Transmission. The factors we want to quantify are colour and haze which means we will need to use Total Transmission.

05. Illuminant

The aim of measuring colour and appearance of this sample is to monitor its appearance as it would be perceived to a customer. For this reason, we are going to use the D65 illuminant for daylight.

06. Observer

As it gives data for a wider field of view and is more commonly used across industries, we are going to use the 10° observer.

07. Colour Scale/s and Indices

Monitoring colour change is important so we are going to keep an eye on both CIE L*a*b* and LCh. We are also going to take readings of the Haze percentage in the sample.

08. Tolerances

Well, here we would have to take a lot of measurements to build up good quality and poor quality databases to give us our tolerances. As we are using our imaginations, we are going to say that our main concern is how much yellow appears in the sample as this would cause it to appear too "orange". We would set tolerances for the a* value to ensure it has enough red and tolerances for the b* value to ensure that the level of yellow stays at an appropriate level.

The next step would be to put this specification into practice and start to take some measurements. The good thing about specifications such as these is when you are designing them and just starting out, they can be flexible and you can alter them as needed to make sure it suits your application.

It is only when you start communicating the results and specification requirements to your supplier that you need it to be finalised and perfect. Your supplier won't like you if you keep changing your mind about tolerances or illuminants every week. I can imagine they wouldn't be thanking you for the headaches you will give them!

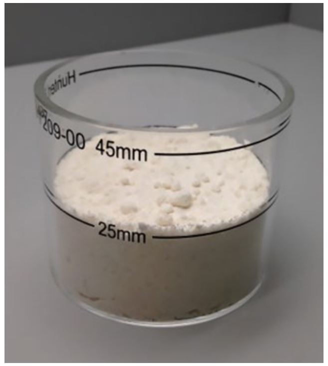
Example 2

Another example for setting supplier specifications. (Because practice makes perfect.)

For this example, you are the manufacturers of flour, the appearance of which is as seen in the image to the right.

The main issues that have been found with this product is that it can appear yellow.

Issues such as these can call into question the quality of the ingredients and the efficiency of the manufacturing process.



Supplier Specification number 2!

01. Sample Preparation

As the sample is a powder, we will place it in a glass sample cup. This allows for the sample to be measured from below when placed on the top of an instrument and, because it is a powder, it can form a relatively uniform surface when placed against the glass.

02. Amount of measurements

With the physical composition of flour, it is not likely to lie completely flat and uniform and there will be some obvious lines and shadowing. Because of this we would recommend taking an average of 3 measurements, turning the sample between measurements to allow for a more accurate representation of the entire sample.

03. Geometry

As we are measuring the reflected colour and looking through glass, we will use an instrument with directional 45°/0° geometry.

04. Mode

For this application, we need to take a measurement of the entire base of the sample cup. This particular sample cup has a diameter of 64mm, so we will need to use a measurement port of 64mm.

05. Illuminant

The aim of measuring colour and appearance of this sample is to monitor its appearance as it would be perceived by a customer. For this reason, we are going to use the D65 illuminant for daylight.

06. Observer

As it gives data for a wider field of view and is more commonly used across industries, we are going to use the 10° observer.

07. Colour Scale/s and Indices

Monitoring colour change is important so we are going to keep an eye on both CIE L*a*b* and a Yellowness Index: YI E313, to monitor any increases in yellowness.

08. Tolerances

Well, here we would have to take a lot of measurements to build up good quality and poor quality databases to give us our tolerances. As yellowness is the main concern, tolerances should be set for the Yellowness Index.

Again, the next step would be to put this specification into practice and start to take some measurements. This specification can be modified as needed to cater to different types of flour as required.

Example 3

Getting bored yet? Example number 3 is different to the other two (obviously, or we could have just copied and pasted it in and hoped you wouldn't notice.)

For this example, you are the manufacturers of crisps, the appearance of which is as seen on the image to the right..

The main issues that have been found with this product is that they can appear too light or too dark.

Issues such as these can call into question the efficiency of the cooking process.

Supplier Specification number 3!

01. Sample Preparation

Crisps are not a uniform product so getting a reliable representation of an entire batch from measuring one or two crisps won't work. Instead, how about taking periodic measurements on the line itself?. That way you won't need any specific sample preparation; just the normal crisps going about their everyday business.

02. Amount of measurements

With this on-line measurement, we wouldn't say put a definite number of measurements to your analysis. Instead, have the instrument take a measurement once every 10 seconds or so, depending on the speed of the line.

03. Geometry

For this application, we would aim for a different geometry altogether as it is on- line. We would use 0°/30°.

04. Mode

For non-contact measurements, the instrument will work in reflectance mode with a measurement period of 10 seconds.

05. Illuminant

The aim of measuring colour and appearance of this sample is to monitor its appearance as it would be perceived to a customer. For this reason, we are going to use the D65 illuminant for daylight.

06. Observer

As it gives data for a wider field of view and is more commonly used across industries, we are going to use the 10° observer.

07. Colour Scale/s and Indices

Monitoring lightness change as well as colour is important so we are going to keep an eye on the CIE L*a*b* results, paying particular attention to the L* values.

08. Tolerances

Well, here tolerances should be easy to set as there is such a large number of samples going through. Visual assessment should be done on the line to correspond with the colour analysis, therefore pinpointing when a sample isn't up to scratch. Tolerances can be set by this and a traffic light system can even be put in place with lights giving clear indications of when the product is good, straying out of tolerance and bad.

Again, the next step would be to put this specification into practice and start to take some measurements. As it is a fairly straight forward process, it won't take long to have the system working correctly and helping with quality control.

Colour can also relate to various processes and physical properties of samples. For example, colour can be an indicator of various carcinogens such as Acrylamide found in some foodstuffs.

Example 4

Final example, number 4.

For this example you are manufacturers of opaque plastic pellets of different colours, similar to the ones shown below.

The main issues that have been found with this product is that the colour can appear inconsistently saturated.

Issues such as these can call into question the efficiency of the colour dosing process.

Supplier Specification number 4!

01. Sample Preparation

Due to the non-uniform sample type, the most reliable way of measuring these pellets would be to use a glass sample cup that would be filled with the pellets. The sample cup should be the same size for all samples of each colour and should cover the entire base of the cup.

02. Amount of measurements

We would take an average of 3 measurements per sample, turning the sample cup between measurements to provide a good representation of the overall colour of the samples.

03. Geometry

For this application we would use a 0°/45° or 45°/0° geometry.

04. Mode

This instrument works in reflectance mode and should use a viewing area that matches the size of sample cup being used. Typically, a 64 mm diameter sample cup is more commonly used.

05. Illuminant

The aim of measuring colour and appearance of this sample is to monitor its appearance as it would be perceived to a customer. For this reason, we are going to use the D65 illuminant for daylight.

06. Observer

As it gives data for a wider field of view and is more commonly used across industries, we are going to use the 10° observer.

07. Colour Scale/s and Indices

As colour saturation seems to be an issue, we will be looking into the CIE LCh colour scale, paying particular attention to the C values which show the chroma or saturation of the sample.

08. Tolerances

Tolerances can be set on the CIE LCh colour scale, again paying particular attention to the C value. You would need to set a highest and lowest possible tolerance as, if the C value is too low, the colour wouldn't appear as vibrant but if it is too high, the sample will be saturated with colour. There is a point at which the human eye cannot notice any further colour differences with the addition of more colour, so it will just waste money to add more to the pellets.

Glossary of Terms

Well, we've got to this section of the book and we are well aware that a lot of technical terms and jargon have been used and at some point we're sure you didn't have a clue about what something meant. Either that or you're only partway through and are checking about the meaning of a term before carrying on. (Very sensible idea.)

If you do happen to be only partway through, don't worry, there are no spoilers here. Just an awful lot of helpful definitions. There are a lot of them but they are all in alphabetical order so feel free to skip the irrelevant ones.

A

Acrylamide
Acrylamide is a chemical that can form in some types of foodstuffs when subjected to high-temperature cooking or heating processes. Acrylamide is a known carcinogen in animals.

ADMI
ADMI stands for American Dye Manufacturer's Institute and is a colour index used to monitor the colour of wastewater as an indicator of water quality.

APHA/PtCo/Hazen
APHA stands for American Public Health Association. This colour scale acts as a yellowness index, allowing for accurate measurements of transparent liquids. The APHA colour scale ranges from 0 (clean water) to 500 (distorted waste water).

The PtCo or Platinum Cobalt Colour Scale is equal to the APHA Colour Scale as they are both used predominately to measure the colour and quality of water.

The Hazen Colour Scale is again equal to the APHA and PtCo although can sometimes be referred to as Hazen Colour or 1500 Hazen Colour. If this is the case then the range often goes above the 500 units associated with APHA.

These colour scales play an important role in a range of industries as they can quantify trace amounts of yellowness caused by exposure to light or heat, an error in processing or the presence of impurities.

ASBC Turbidity
ASBC Turbidity is based on a simple spectral method that measures absorbance at two points – one in the blue region (430nm) and one in the red region (700nm). If the absorbance in these two regions is significantly different then a sample is said to be turbid (large amount of scattered light). If there is little to no difference then a sample is said to be free of turbidity.

ASTM D1500
ASTM D1500 is the standard test method for the ASTM colour of Petroleum Products.

C

Chroma
Also known as saturation, the term chroma is used to describe how saturated with colour the sample is.

CIE L*a*b*
The CIE L*a*b* colour scale is also known as the CIE 1976 L*a*b* Colour Space and gives data for samples depicting how light to dark, red to green and yellow to blue a sample is.

CIE LCh
The CIE LCh colour scale gives numerical data for samples with regards to lightness, chroma and hue. The higher the Lightness value, the lighter the sample appears. The higher the Chroma value, the more saturated with colour the sample is (as opposed to grey.) The Hue value is depicted as circular angle degrees; 0° being red, 90° being yellow, 180° being green and 270° being blue.

CIE Observer Functions
The CIE $\bar{x}$, $\bar{y}$ and $\bar{z}$ functions were derived to be able to quantify the red, green and blue cone sensitivity in the eye of the average human observer.

CIE XYZ
The X, Y and Z values are tristimulus values that are calculated by using the $\bar{x}$, $\bar{y}$ and $\bar{z}$ standard observer functions that quantify the red, green and blue cone sensitivity of the eye, the illuminant and the reflectance or transmittance of a sample.

Colorimeter
An instrument for measuring the colour and intensity of colour of a variety of sample types.

D

Delta L* (dL*) / (dL) / (ΔL*) / (ΔL)
This is the difference between the L* value of a standard and that of a sample.

Delta a* (da*) / (da) / (Δa*) / (Δa)
This is the difference between the a* value of a standard and that of a sample.

Delta b* (db*) / (db) / (Δb*) / (Δb)
This is the difference between the b* value of a standard and that of a sample.

Delta E* (dE*) / (dE) / (ΔE*) / (ΔE)
This is the total difference between a standard and a sample.

Glossary of Terms

D

Delta E CMC / (dE CMC) / (ΔE CMC)
Delta E CMC is a 3-dimensional elliptical tolerance developed by the Colour Measurement Committee of the Society of Dyers and Colorists that defines the colour difference between a standard and a sample. Colour differences calculated using the CMC method are believed to correlate better with visual assessment than other colour differences. The CMC ellipse is unique in that the shape of it changes depending on where the standard is in colour space.

Delta XYZ / (dXYZ) / (ΔXYZ)
This is the difference between the CIE XYZ values of a standard and that of a sample. Each difference will be written as dX, dY and dZ.

Delta Yxy / (dYxy) / (ΔYxy)
The difference values for Yxy depict the difference between the Y, x and y values for a standard and a sample.

E

EBC
EBC is very similar to the SRM (Standard Reference Method) for beer colour specification.

SRM measures the absorbance of beer at a wavelength of 430nm with ½ inch path length. The absorbance is then multiplied by 10 to get the SRM value (also known as degrees Lovibond.)

SRM can be converted into EBC using the following calculations:

SRM = EBC / 1.97
EBC = 1.97 x SRM

European Pharmacopeia (EP)
A regional pharmacopeia that provides quality standards throughout the pharmaceutical industry to control the quality of medicines and other pharmaceutical products.

G

Gardner
The Gardner Colour Scale is a single number, one-dimensional colour scale to measure the shade of the colour yellow. This scale ranges from pale yellow to red in shade with numerical values ranging from 1 – 18.

H

Haze
In a transparent solid or liquid sample, haze is the term given to a texture or appearance that causes a scattering of light in that sample.

Hue
Hue is the term for the general colour of a sample, i.e. red, green, blue etc.

Hunter Lab
A uniform colour scale devised by Hunter in 1958 for use in a colour difference meter.

I

Illuminant
Illuminants are the different variations in light sources that a sample can be measured under and are normally written with a corresponding observer, for example D65/10 or C/2. They are as follows:

D65 – Average Daylight

A – Tungsten

F02 – Fluorescent

C – Daylight

L

Lightness
A term used to describe how light to dark a sample is.

O

Observer
The CIE Standard Observer was originally developed by conducting an experiment that used a 2° observational view. When it was discovered that the cones in the eye that are responsible for seeing colour were spread further than first thought, the experiment that first gave the 1931 2° Standard Observer was re-done to give the more commonly used 1964 10° Standard Observer.

Glossary of Terms

S

Saybolt
The Saybolt Colour Scale is used in the measurement of clear to slightly yellowish samples as its colour range is similar to that of the APHA/PtCo/Hazen Colour Scales. It is primarily used in the analysis of light-coloured petroleum products.

Spectrophotometer
A Colorimetric Spectrophotometer uses a light source to illuminate a sample. The reflected light then passes through a grating which breaks the light down into its spectral components. The sample signal at each wavelength is then determined as the light falls onto a diode array. This spectral data is then sent to an internal processor which allows for multiplication with illuminant and observer values to give CIE XYZ colour values. With the use of either external or built in software, the spectrophotometer is able to give data in a wide range of colour scales and indices with varying illuminant and observers.

Standards
Four types of standards are available, depending on the measurements and data needed.

> Working
Used when several different standards and samples are measured in a single session. A working standard is measured immediately prior to measuring its corresponding samples, such as comparing the end of one roll to the beginning of another. Its measurement values will be overwritten the next time a standard is read using this product setup.

> Physical
Used when an actual product specimen is available that represents the target colour to which samples will be compared on a regular basis. A physical standard is measured and stored in the product setup for as long as desired.

> Numeric
Used when a physical specimen does not exist for measurement, but the target colour values are known from previous measurements. The colour values for a numeric standard are entered and stored in the product setup for as long as desired.

> Hitch
Used to alter the readings made on a spectrophotometer to better correlate to another colour measurement instrument. A specific standard with known colour values from the other (reference) instrument will then be read with the current instrument and that reading manually adjusted within the product setup to match the reference instrument. The modified standard is stored in the product setup for as long as desired.

Standardisation
The process of preparing a spectrophotometer or colorimeter for colour and appearance measurement. Standardising or "calibrating" a spectrophotometer "scales" the instrument by setting the bottom and the top of the L value on the colour measurement scale.

T

Transmission
When light is shone through a sample, there are three types of transmitted light that a spectrophotometer can use in its calculations: Regular, Diffuse and Total. Regular transmission is transmitted straight through a transparent solid or liquid sample. This is where transmitted colour is primarily seen.

Any surface texture in the sample can cause the light to scatter or diffuse. Diffuse transmission also contains the colour of the sample.

Total transmission is the combined transmission of the Regular transmission and Diffuse transmission.

Tristimulus
Tristimulus values give the amount of the 3 colours red, green and blue that are combined to form other colours.

Turbidity
The turbidity value for a sample depicts how distorted the clarity of a sample is as a result of bubbles present in the liquid. These are commonly written as NTU, National Turbidity Units.

W

Whiteness Indices
Whiteness indices, such as WI E313, are used to quantify the whiteness of a sample. For samples that should be a pure white, low whiteness index values can indicate contamination of the product.

Y

Yellowness Indices
The Yellowness indices, such as YI E313 and YI D1925 are used to quantify traces of yellowness in clear samples. This yellowness can be the indicator of contamination to the product or evidence of the presence of impurities.

Y Transmittance
Y Transmittance is another name for the 1924 CIE Luminosity or Brightness Function which quantifies the way people perceive the relative brightness of equal energy spectral hues. The Y Transmittance value quantifies the overall transmittance of transparent colours.

Yxy
CIE xy are chromaticity coordinates that depict the colour of a sample. The Y value represents brightness or how light to dark a sample is. If looking to measure luminance, Y / 100 = Beta value which represents the luminance of a sample.

Get In Touch

We would really love to hear from you so we've made it very easy to get in touch.

Office Telephone: +44 (0) 116 2691240

(For the serious, sensible conversations about colour measurement or for trying to get us to switch energy providers.)

Mobile Telephone: +44 (0) 7958 807971

(If you prefer text message or WhatsApp. Perhaps if you haven't had your coffee yet and don't fancy a chat. We can sympathise.)

Email: hello@stotto.com

(For those that don't fancy talking at all or should be working but have a secret desire to learn more about colour measurement surreptitiously.)

Website: www.colourmeasure.com

(If you were in the slightest bit curious about who we are and what we do, the website is always a safe bet.)

Of course, we are more than happy to contact you but you will have to meet us halfway and send us your details somehow. The above methods are preferred but we'd never say no to a carrier pigeon or telegram.

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In a world divided by opinion, where perfection is the most sought-after commodity and quality issues are met with extreme distaste, a group of heroes known to mankind as the Quality Managers are on a mission to make the world a better place.

On their adventures they encounter formidable foes, including the sinister Supplier Specifications, and confront the obstacles they face armed with nothing but their desire for improvement.

They engage in many battles and face many trials but, through their superior knowledge of colour and appearance, they work tirelessly to bring about the reign of excellence and the demise of imperfection.

Travel with the Quality Managers as they gather knowledge of colour and appearance. Join them in their fight against flaws and their dual against defects and cheer them on as they win the war against inadequacies.

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