Colour and gloss

15 November 2016

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Colour and gloss

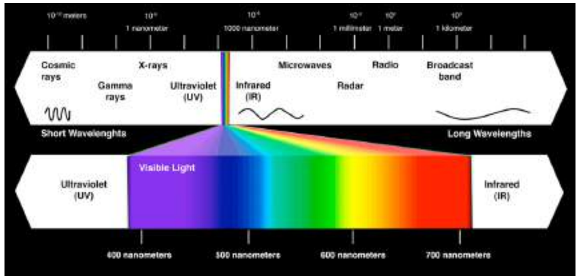
Why do we measure colour?

1. To help with the identification of materials
2. To map the presence of materials across an object
3. To measure and predict the change in colour of objects
4. To monitor the change in colour in objects

Colour and gloss

Colour theory

Colour is a phenomenon associated with the wavelengths of radiation to which the human eye is sensitive



This radiation is termed 'visible light' and is characterized by wavelengths between 400 and 700 nanometers

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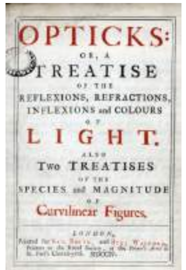
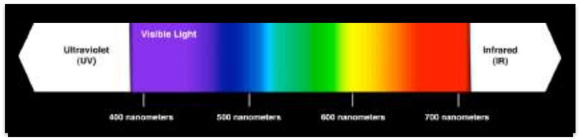
Colour theory

Although the different wavelengths below are shown in particular colours, these relate to the names we give to the sensations produced in the eye when it detects light rays of these wavelengths

"the Rays to speak properly are not coloured. In them there is nothing else than a certain Power and Disposition to stir up a Sensation of this or that Colour" (Newton, *Opticks* 1704).


OPTICKS:
OR, A
TREATISE
OF THE
REFLEXIONS, REFRACTIONS,
INFLEXIONS and COLOURS
OF
LIGHT.
ALSO
Two TREATISES
OF THE
SPECIES and MAGNITUDE
OF
Curvilinear Figures.



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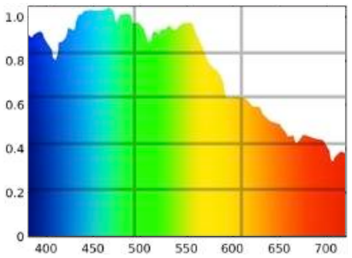
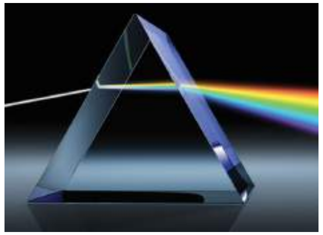
Colour theory

We name colours according to the way they interact with the ‘white light’ under which we normally view objects





White light (daylight in this example) contains radiation over a range of wavelengths in the visible region

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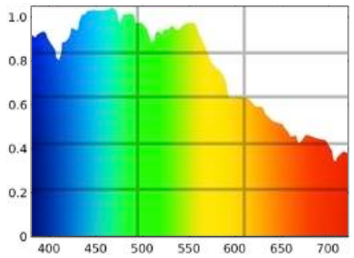
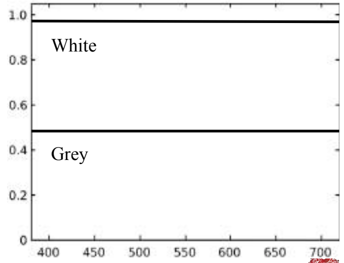
Colour theory

Objects can modify the colour of the light that is incident upon them by (for example) reflection, absorption or transmission. We can graph the way in which various colours interact with light at different wavelengths





If we focus on reflection, a white or grey object will not change the ratio of radiation reflected at different wavelengths

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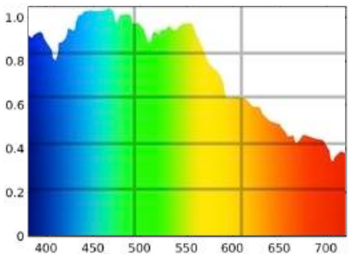
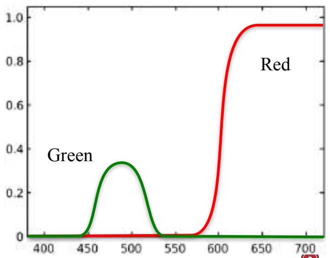
Colour theory

Surfaces that differentially reflect certain wavelengths of light change the ratio of radiation reaching the eye, producing sensations of colour by – for example – reflecting mostly light in the red or green regions in these examples





A piece of red glass would have a similar **transmittance** as the **reflectance** seen here for a red surface

Colour and gloss

Measuring colour

1. Comparative methods – colour atlases
2. Spectrophotometric methods – based on spectral data
3. Colorimetric methods – based on the way in which the eye detects colour
4. Imaging methods – spectrophotometric or colorimetric, but measuring across large areas

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Measuring colour: comparative methods

The spectral properties of the colour are not considered

Colours are matched by eye to reference samples – from colour atlases

Relies on the colour vision of the observer, but does not require an understanding of the principles of colour vision

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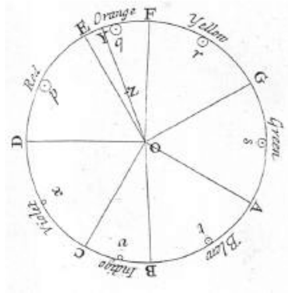
Measuring colour: comparative methods



Isaac Newton, *Opticks*, S. Smith & B. Walford, London (1704) Book I, Part II

Johann Wolfgang von Goethe, *Zur Farbenlahre*, Verlag Cotta, Tübingen (1810)

Historically, many colour order systems are based on a circular depiction of different hues, usually corresponding to the order of the colours in the spectrum

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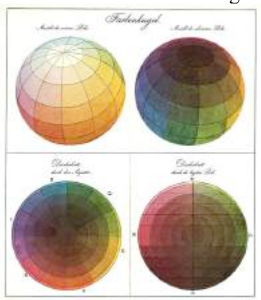
Measuring colour: comparative methods



Phillip Otto Runge, *Die Farben-Kugel, oder Construction des Verhaeltnisses aller Farben zueinander*, Verlag Perthes, Hamburg (1810)

Michel Eugène Chevreul, Des couleurs et de leurs applications dans les arts industriels, J.-B. Baillière et fils, Paris (1864)

Later systems were more scientifically based and included a black–white component (achieved in the case of Chevreul's atlas through a series of plates with different lightnesses)

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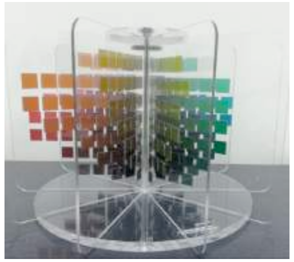
Measuring colour: comparative methods



Two significant current colour systems are the Munsell system and the NCS system

Both provide atlases of colours against which to make comparisons (although these are increasingly computerized)

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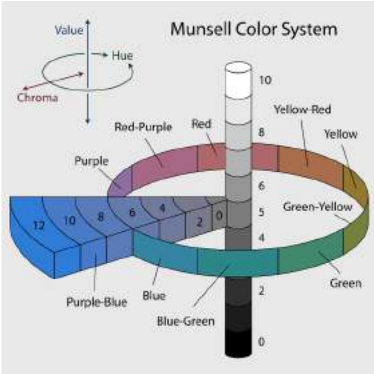
Measuring colour: comparative methods



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Measuring colour: comparative methods

The Munsell system was recently used at the British Museum to categorize thread colours found in a number of pre-Columbian Andean workbaskets. The project involved partner museums in Europe and South America, so the use of a common, readily-available standard aided consistency

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Measuring colour: comparative methods

The Munsell soil chart system is frequently used by archaeologists and conservators in the field to classify pottery sherds where instrumental methods would not be appropriate

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Measuring colour: comparative methods

Although the use of colour atlases is a **qualitative** method of assessing colour, its effectiveness can be improved by

1. Use of a standardized white light for comparisons

2. An adequate level of illumination

3. Viewing the object and the colour standard in a glare-free environment

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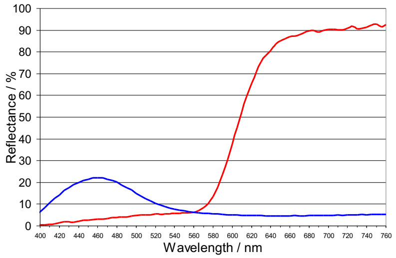
Measuring colour: spectrophotometric methods

Spectrophotometric measurement is based on splitting white light into its component wavelengths using a prism or grating, then illuminating the object with each wavelength of light in turn.

The amount of light reflected at each wavelength is measured, allowing the spectrometer to return a graph – or spectrum – showing the reflectance of the object at each wavelength



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Measuring colour: spectrophotometric methods

While comparative methods are **qualitative**, spectrophotometric and colorimetric methods aim to be **quantitative**. Quantitative, reproducible results depend on a number of factors, e.g.

1. The calculation of colour that is independent of the light source
2. Calibration of the equipment to known wavelength, reflectance and colour standards
3. Definition of the measuring area with respect to the inhomogeneity of the object
4. Definition of the geometry for colour measurement
5. Sufficient wavelength resolution

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Measuring colour: spectrophotometric methods

Discounting the effect of the light source

Generally by measuring the spectrum of a white reference material with a known spectrum alongside the sample, either:

1. At the same time (a so-called dual beam instrument)
2. Consecutively, and using software to correct the sample spectrum with respect to the white reference material

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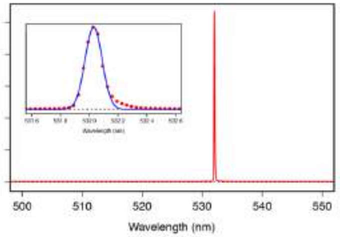
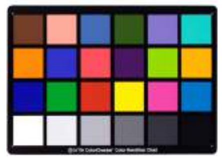
Measuring colour: spectrophotometric methods

Calibration of the equipment to known wavelength, reflectance and colour standards





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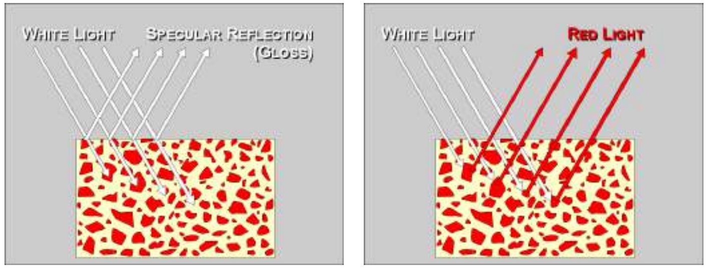
Measuring colour: spectrophotometric methods

Definition of the measuring area with respect to the inhomogeneity of the object

Colour and gloss

Measuring colour: spectrophotometric methods

Definition of the geometry for colour measurement



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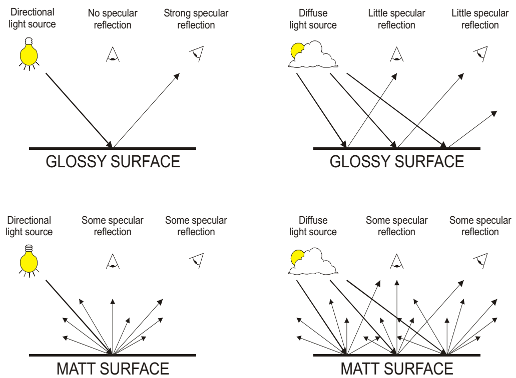
Measuring colour: spectrophotometric methods

Definition of the geometry for colour measurement



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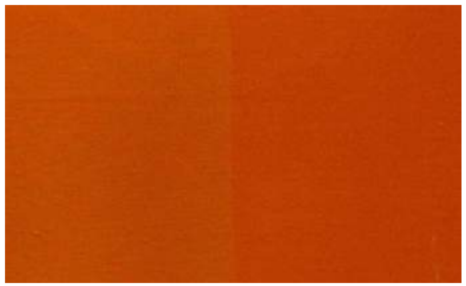
Measuring colour: spectrophotometric methods

Definition of the geometry for colour measurement



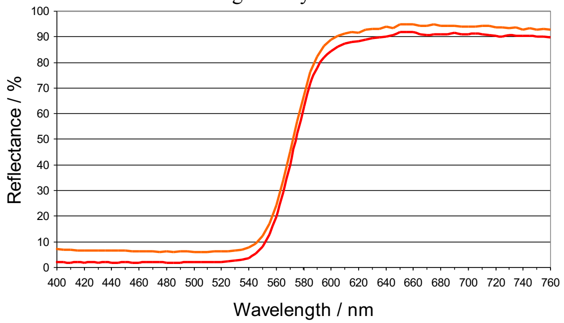
Matt Gloss

Viewed under diffuse light

Colour and gloss

Measuring colour: spectrophotometric methods

Definition of the geometry for colour measurement

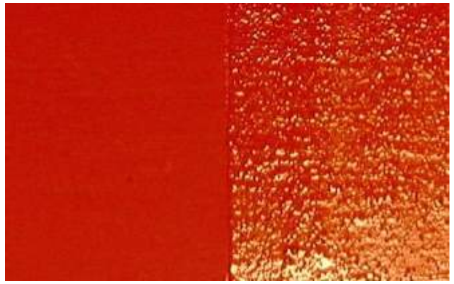


Reflectance curves for gloss and matt vermilion samples: viewed under diffuse light with specular reflection included

Colour and gloss

Measuring colour: spectrophotometric methods

Definition of the geometry for colour measurement



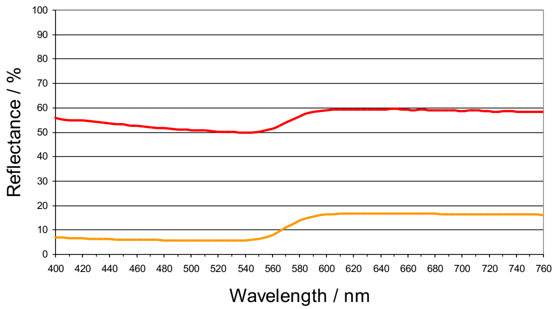
Matt Gloss

Viewed under directional light

Colour and gloss

Measuring colour: spectrophotometric methods

Definition of the geometry for colour measurement

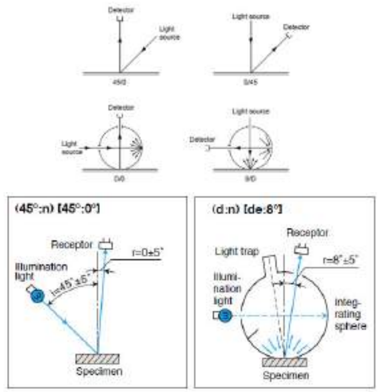


Reflectance curves for gloss and matt vermilion samples: viewed under directional light with specular reflection included

Colour and gloss

Measuring colour: spectrophotometric methods

Definition of the geometry for colour measurement: gloss exclusion



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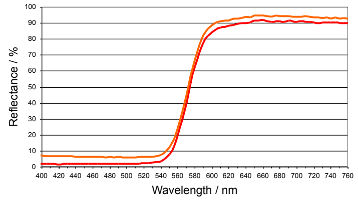
Measuring colour: colorimetric methods

The spectra produced by the methods we have looked at so far, contain a great deal of information about the reflection and absorption properties of objects and – as these are related to the molecular structure of materials – can be very useful for material identification, as we will see later

However, even for the experienced, spectra do not give particularly straightforward information about how a colour appears to us and it is quite difficult to use spectra to give simple information about changes in colour



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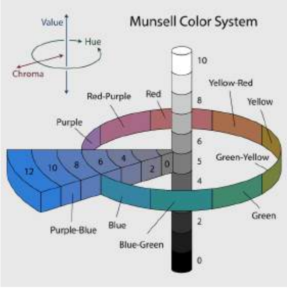
Measuring colour: colorimetric methods

Colorimetric measurement relies on converting the information to a set of colour coordinates. It is usual to specify a colour with three coordinates – so that it can be represented by a point in 3D space. These are analogous to the colour spaces represented in the colour atlases that we saw earlier



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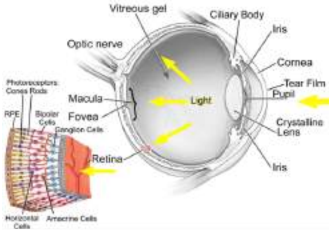
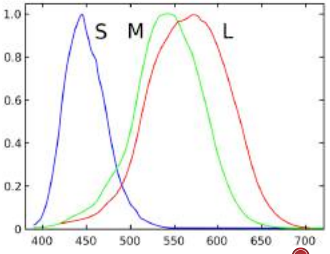
Measuring colour: colorimetric methods

Standardized colorimetric measurements are based on the systems published by the Commission Internationale de L'Eclairage (CIE). These systems derive from an understanding of the way in which the human eye and brain process colour information.





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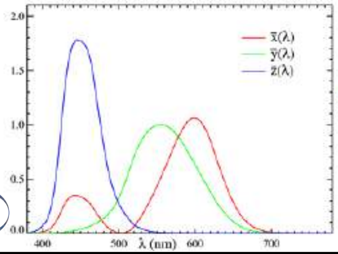
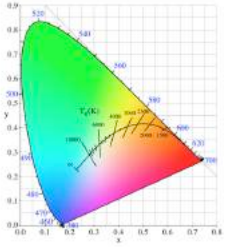
Measuring colour: colorimetric methods

The CIE defines a set of base cone responses for colour vision, shown below, first codified in 1931. With some revision, they still form the basis of modern colorimetry

The commonly-encountered xy diagram is a relatively simple representation of the ratio of stimulation of the red, blue and green photoreceptors in the eye





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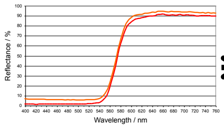
Measuring colour: colorimetric methods

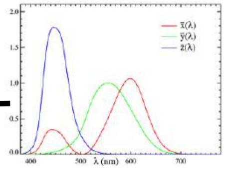
The coordinates in the xy diagram can be derived from spectral information mathematically by applying the CIE spectral functions:



$$X = \sum_{400}^{700} s(\lambda)E(\lambda)\bar{x}(\lambda)$$

$$Y = \sum_{400}^{700} s(\lambda)E(\lambda)\bar{y}(\lambda)$$

$$Z = \sum_{400}^{700} s(\lambda)E(\lambda)\bar{z}(\lambda)$$



$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

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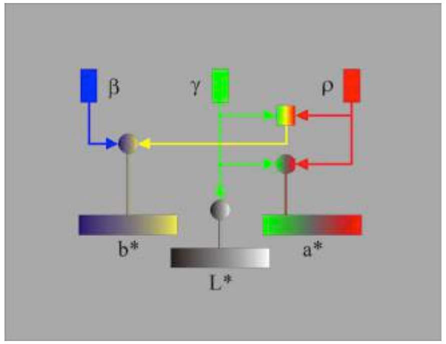
Measuring colour: colorimetric methods

The currently-used set of CIE colour coordinates is the so-called CIELab system. It is designed to mirror the way in which colour signals are processed by the eye and brain



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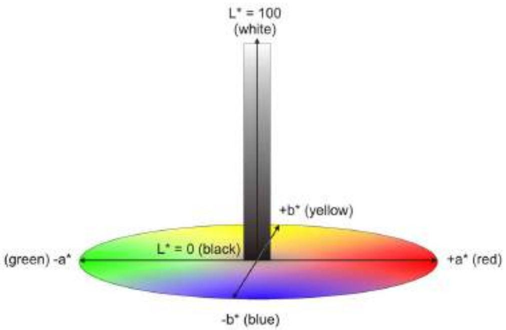
Measuring colour: colorimetric methods

The CIE Lab coordinates thus represent, in a numerical form, perceptual attributes of a colour: lightness (L*), red–greenness (a*) and yellow–blueness (b*)



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Measuring colour: colorimetric methods

The CIELab data can be derived mathematically from the XYZ data seen previously

$$L^* = 116 f(Y/Y_n) - 16$$

$$a^* = 500\left[f(X/X_n) - f(Y/Y_n)\right]$$

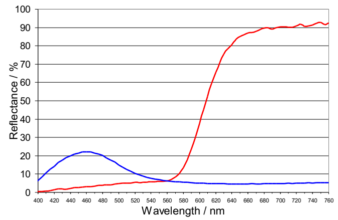
$$b^* = 200\left[f(Y/Y_n) - f(Z/Z_n)\right]$$

Chrome red

L* 48.35
a* 57.02
b* 49.64

Azurite

L* 33.99
a* 2.00
b* -29.67



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Measuring colour: colorimetric methods

The microprocessors in modern spectrophotometers usually calculate Lab directly – as well as a whole range of other colour data

Colour and gloss

Measuring colour: colorimetric methods

Some older colorimeters use filtered photocells – matched as closely as possible to the CIE x, y and z curves seen earlier.

Modern colorimeters tend to incorporate spectral sensors and convert these data to colorimetric data in the same way as spectrophotometers

Colour and gloss

Measuring colour: colorimetric methods

In common with spectrophotometry, colorimetry is potentially a **quantitative** method, although quantitative, reproducible results again depend on:

1. High quality match of sensors in meter to CIE standards – or an accurate transform from spectral measurements to CIE data ('phone apps rely on the colour camera)

2. Calibration of the equipment to known reflectance or colour standards (use of white standards)

3. Definition of the measuring area with respect to the inhomogeneity of the object (careful selection of measuring area diameter according to object)

4. Definition of the geometry for colour measurement (exclusion of gloss if appropriate)

Colour and gloss

Measuring colour: imaging methods

This will be discussed in greater detail later in the week

Uses a camera or a scanned point sensor to image a large area of an object

Each pixel in the camera or point at which the sensor makes a reading corresponds to an individual colour measurement

Filters or a grating are used to divide the visible spectrum into a number of bands

Three band cameras or scanners are effectively acting as imaging colorimeters

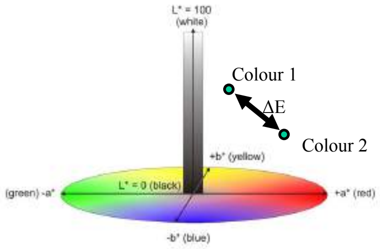
Systems using a larger number of bands are often described as imaging spectrometers

Colour and gloss

Measuring colour difference

Many applications of colour measurement in the examination of objects require colour difference to be quantified

There are CIE standards and units for the measurement of colour difference. The basic unit of colour difference is denoted by the symbol ΔE, which – at its simplest – is defined as the distance between two points plotted in CIELab colour space

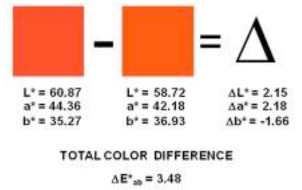


Colour and gloss

Measuring colour difference

The colour difference equation introduced by the CIE in 1976 uses a simple distance between the two points in colour space

$$\Delta E^* = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$$



This colour difference is written as ΔE or, sometimes, as ΔE_{76}

Colour and gloss

Measuring colour difference

In the last 40 years, the colour difference formula has been refined so that a particular value of ΔE corresponds to the same visually perceptible difference whatever region of the colour space is considered

Colour and gloss

Measuring colour difference

The currently used measure of colour difference is the ΔE_{00} unit (developed in 2000), although it is common to see references to the earlier ΔE_{94} or ΔE_{76}

The equations for calculating ΔE_{00} and ΔE_{94} are very much more complex, but fortunately most modern instruments make these calculations for the user

$$\Delta E^*_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C}\frac{\Delta H'}{k_H S_H}}$$

$$\Delta L' = L^*_2 - L^*_1$$

$$\bar{L} = \frac{L^*_1 + L^*_2}{2} \quad \bar{C} = \frac{C^*_1 + C^*_2}{2}$$

$$a'_1 = a^*_1 + \frac{a^*_1}{2}\left(1 - \sqrt{\frac{\bar{C}^7}{\bar{C}^7 + 25^7}}\right) \quad a'_2 = a^*_2 + \frac{a^*_2}{2}\left(1 - \sqrt{\frac{\bar{C}^7}{\bar{C}^7 + 25^7}}\right)$$

$$\bar{C}' = \frac{C'_1 + C'_2}{2} \text{ and } \Delta C' = C'_2 - C'_1 \quad \text{where } C'_1 = \sqrt{a'^2_1 + b^{*2}_1} \quad C'_2 = \sqrt{a'^2_2 + b^{*2}_2}$$

$$h'_1 = \operatorname{atan2}(b^*_1, a'_1) \mod 360°, \quad h'_2 = \operatorname{atan2}(b^*_2, a'_2) \mod 360°$$

Colour and gloss

Measuring colour difference

The accuracy of colour difference measurements will be influenced by instrumental considerations and calibration, but in practice the largest single factor that affects the quality of data and the ability to make quantitative measurements is the positional accuracy of remeasurement, particularly if these are made some time apart – as is often case in monitoring experiments.

Templates are frequently used to reposition the measuring head / instrument at the same position as previously, or the position can be determined in relation to features in a textile design, cracquelure on a painting, etc.

Colour and gloss

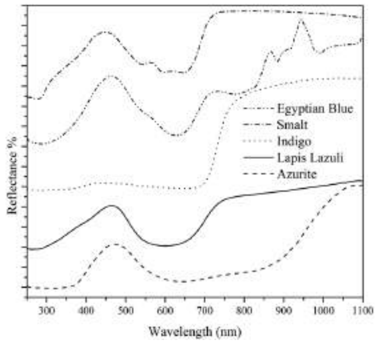
Why do we measure colour?

1. To help with the identification of materials
2. To map the presence of materials across an object
3. To measure and predict the change in colour of objects
4. To monitor the change in colour in objects

Colour and gloss

Identification of materials

Most identification relies on spectral measurements. In some cases the features in the visible spectrum alone can be sufficient to differentiate within a limited number of possibilities, e.g. historically-available blue pigments



Colour and gloss

Identification of materials

Extending the measurement range into the near infrared increases the number of characteristic absorptions covered and increases the usefulness of the technique

Fibre-optic reflectance spectrometry (FORS) has been used – in conjunction with a library of reference spectra – to identify pigments on paintings and manuscripts

Colour and gloss

Mapping materials

Using imaging techniques to cover large areas of an object

Mapping is normally achieved using hyperspectral techniques with many bands

Colour and gloss

Measuring and predicting change

Often applied to assess the implication of light exposure or the effects of conservation treatment

Before and after measurements made to look at differences, so positional accuracy important to have comparable readings

Colorimetry frequently used, as detailed spectral information is not (always) relevant

Colour and gloss

Measuring and predicting change

Tests on surrogate materials to categorize vulnerability to light damage




Colour and gloss

Measuring and predicting change

Microfading / micro colour measurement on objects to test vulnerability to light damage

Colour and gloss

Measuring and predicting change

Tests are frequently made to determine how a conservation treatment or material will affect the colour of an object – either the immediate effects or as a result of longer-term ageing of conservation materials, such as polymeric consolidants and adhesives

Colour and gloss

Monitoring colour change

Long-term periodic measurement of objects – generally to look at the effect of storage and display on their colour

Before and after measurements are made to look at differences, often with a very long time interval between readings, so positional accuracy is critical if readings are to be comparable

For over 70 years, The National Gallery in London has used colorimetric, spectrophotometric and imaging methods to look at long term changes in colour to paintings

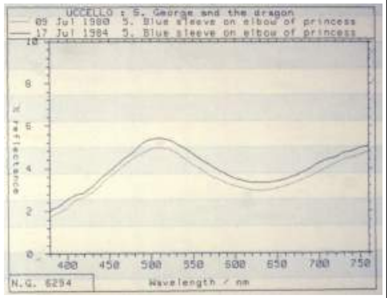
Colour and gloss

Monitoring colour change: colorimetric methods

Hollyhocks and Other Flowers in a Vase
1702–1720, Jan van Huysum [NG 1001]

Colour and gloss

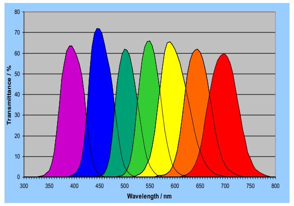
Monitoring colour change: spectrophotometric methods



St George and the Dragon
*c.*1470, Paolo Uccello [NG 6294]

Colour and gloss

Monitoring colour change: imaging methods



Colour and gloss

Monitoring colour change: imaging methods

The Virgin and Child in an Interior,
Workshop of Robert Campin [NG 6514]

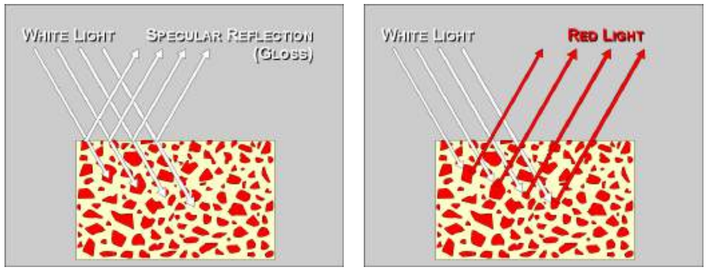
Colour and gloss

Measuring gloss

Colour and gloss

Measuring gloss

While the presence of gloss might be a nuisance when measuring colour, there are occasions on which it is useful to measure gloss itself

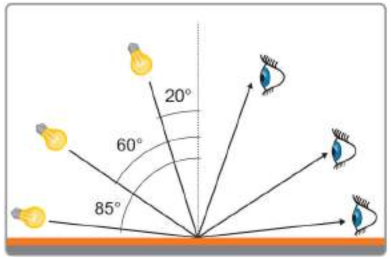


Colour and gloss

Measuring gloss

Standardized procedures are defined for measuring gloss at one of a series of angles

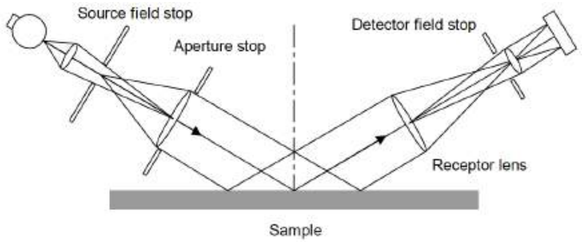
The angle used depends on the application, but 20, 60 and 85 degrees are the most widely accepted standards.



Colour and gloss

Measuring gloss

Instruments comprise a collimated light source and detector, each positioned at the appropriate angle



Colour and gloss

Measuring gloss

Instruments comprise a collimated light source and detector, each positioned at the appropriate angle

Many instruments offer the possibility to measure the gloss at all three standard angles
Those with a fixed angle tend only to measure at 60 degrees.

Colour and gloss

Measuring gloss

Gloss is generally measured in ‘gloss units’ (GU or sometimes Gs)

The gloss of objects is referenced to that of a highly polished black glass standard, which is considered to have a value of 100 GU

For measurements at 60 degrees gloss is classified as follows:

<10 GU = low gloss
10–70 GU = medium gloss
>70 GU = high gloss

High gloss is better measured using 20 degree illumination
Low gloss is better measured using 85 degree illumination

Colour and gloss

Why do we measure gloss?

To measure, predict and monitor the change in gloss on objects

Colour and gloss

Measuring change in gloss

We often study the way in which treatments – particularly consolidants or fixatives – affect gloss, and use the results of testing to select the least visually intrusive materials

Colour and gloss

Contact / non-contact measurement

While surface colour and gloss measurement are essentially non-destructive and non-invasive, they are not always non-contact. This may or not matter, depending on how robust is the surface of the objects or test sample

Imaging or scanning methods are generally non-contact

Spectrophotometric methods vary, with FORS and the spectrophotometer at the National Gallery, London developed specifically to allow *in situ* non contact measurement

Many colorimeters work best if placed on the surface, and repeatability is improved if they are used in this way

Colour and gloss

What else might we measure?

1. Transparency, scatter and turbidity of materials – and changes in these properties – often used in the context of coatings, varnishes and other conservation materials

2. Yellowness – as one of the most common changes to varnishes and polymeric conservation materials is yellowing with age.