# COLOUR THEORY- UNDERSTANDING AND WORKING WITH COLOUR



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Cover image for Colour Theory: Understanding and Working with Colour

# Colour Theory- Understanding and working with colour

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# what is colour?

Colour is how we describe the visible features of an object by its **hue**, **lightness**, and **saturation**. In physics, we identify colour by measuring a range of wavelengths known as the **visible spectrum** (See Figure 0.1). We also call this **light** or **electromagnetic radiation**. The human eye perceives these visible wavelengths as different colours.

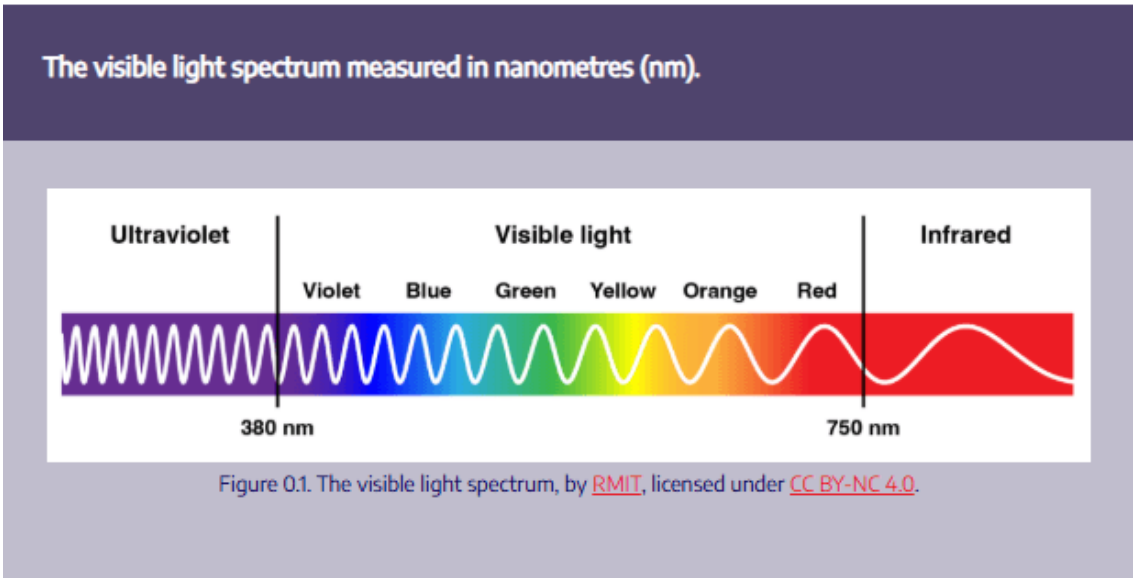



Figure 0.1. The visible light spectrum, by RMIT, licensed under CC BY-NC 4.0.

In this open educational resource, you can find information on colour theory divided into three chapters. This resource also includes quizzes to test your knowledge, and practical learning activities to guide users in applications of colour theory for art and design. The content is relevant for anyone working with colour in creative and scientific fields.

Each chapter covers information on the following topics:

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# Colour theory- understanding and working with colour

An open educational resource for learning about colour and it's applications

**What is colour theory?**

Colour theory covers a long history from antiquity to modern times. It includes academic and scientific investigations into how we see and understand colour. It also includes practical applications for using colour in creative work.

This learning resource explains the history of colour theory, how we see colour, and how to use colour systems to mix colour and create colour relationships.

Also included are quizzes and learning activities to guide users in applications of colour theory for art and design. This content is relevant for anyone working with colour in creative and scientific fields.

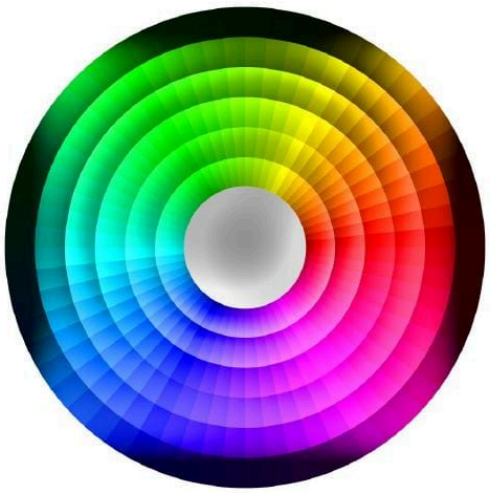


Image attribution: Colour wheel image by Pete Linforth from Pixabay

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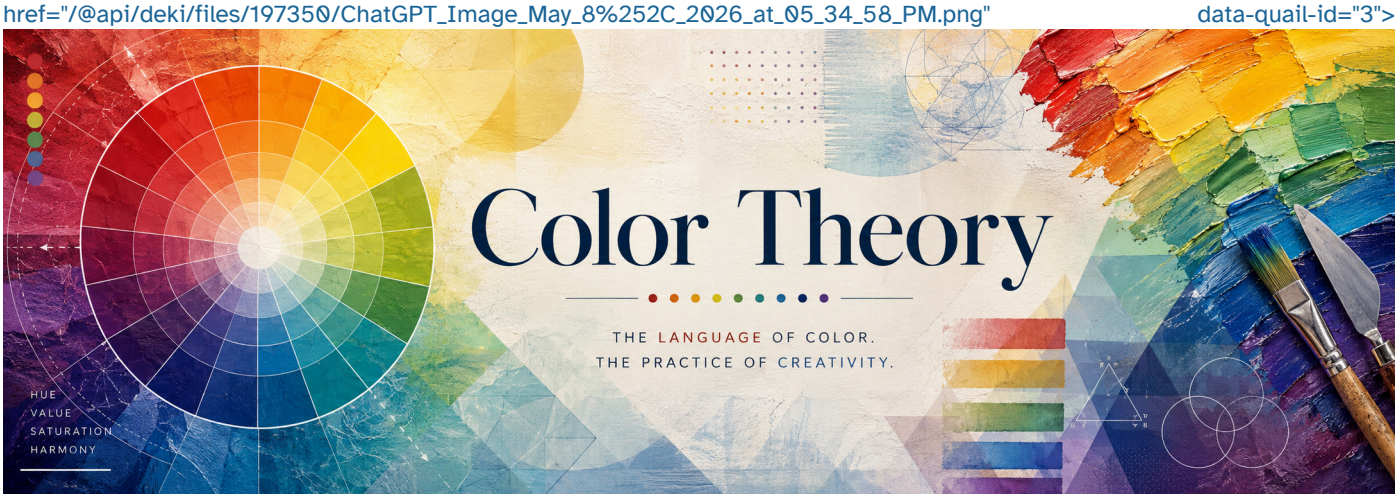
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| Version | Date | Description |
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| Initial Publication | 23/02/2023 | Book published with initial collection of objects available to all users. |
| Second edition | 01/02/2025 | Small corrections and additional interactive self-test quizzes |

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# 1: PART 1- A BRIEF HISTORY OF COLOR

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## Introduction to Color Theory

Color is one of the most powerful and expressive elements of art and design. It shapes how we see, feel, interpret, and respond to the visual world. A single color can create mood, suggest meaning, guide attention, describe light, define form, or communicate emotion before a viewer reads a title or understands the subject matter. In art, color is never simply decorative. It is a visual language.

Color theory is the study of how colors relate to one another and how artists and designers use those relationships to create harmony, contrast, emphasis, depth, symbolism, and visual meaning. Through color theory, we learn how colors are organized, mixed, perceived, and applied. We also begin to understand why certain color combinations feel calm, energetic, dramatic, balanced, joyful, tense, or unsettling.

In this chapter, students will explore the foundations of color, including hue, value, intensity, temperature, and color relationships. The color wheel will serve as an important tool for understanding primary, secondary, and tertiary colors, as well as complementary, analogous, split-complementary, triadic, and monochromatic color schemes. Students will also examine how color changes depending on surrounding colors, lighting conditions, materials, and cultural or personal associations.

For artists, understanding color theory strengthens both technical skill and creative decision-making. A painter may use warm and cool colors to create the illusion of space. A designer may use contrast to make information clear and readable. A photographer may use color temperature to create atmosphere. A digital artist may use saturation and value to direct the viewer's eye. Across all visual disciplines, color helps transform an image from a collection of shapes into a meaningful visual experience.

Color theory also invites experimentation. While there are traditional systems and vocabulary that help us understand color, artists often bend, challenge, and reinvent these ideas. Learning color theory does not mean following rigid rules. Instead, it gives students a foundation for making intentional choices. Once students understand how color works, they can use it with greater confidence, sensitivity, and imagination.

As you move through this chapter, consider color not only as something you see, but as something you experience. Notice how color affects your emotions, your attention, your sense of space, and your interpretation of meaning. By developing a deeper awareness of color, you will strengthen your ability to observe, analyze, create, and communicate through visual art.

1.1: Introduction

1.2: History of Colour Theory
1.3: Cultural Interpretations
1.4: Colour Aesthetics

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# 1.1: Introduction

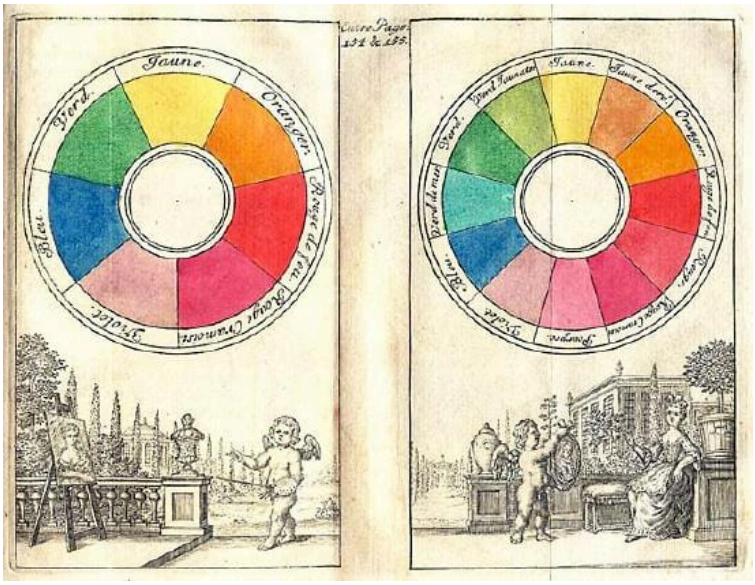



Figure 1.1. Boutet 1708 colour circles. Image attribution: C. B. (probably Claude Boutet or it's editor, Christophe Ballard), Boutet 1708 color circles, marked as public domain, on Wikimedia Commons.

Scientific and theoretical investigations into colour go back thousands of years. Some of the earliest recorded theories of colour come from the ancient Greek civilisation. You will find these in the writings of philosophers such as **Democritus**, **Plato** and **Aristotle**.

Other notable theories of colour developed through the centuries in the work of significant scholars, scientists and artists such as: **al-Kindi**; **Leonardo da Vinci**; **Robert Fludd**; **Isaac Newton**; **Johann Wolfgang von Goethe**; and many more.

This chapter will introduce colour theory history with a summary of selected key scientific developments. Also included are short introductions to cultural interpretations of colour and colour aesthetics.

***Note**: this chapter does not contain a complete listing of all scholars, scientists and artists that have contributed to scientific and artistic fields related to colour theory, rather, it is a condensed timeline with selected notable mentions. See subject guides and references for more information on these topics.*

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# 1.2: History of Colour Theory




Figure 1.2. Sir Isaac Newton. Mezzotint by J. Faber, junior, 1726, after J. Vanderbank, 1725. Image by Wellcome Library, London via Wikimedia Commons, licensed under CC BY 4.0.

## How do we know so much about what colour is? How do we see it and how can we use it?

A progression in our understanding of colour through many versions of practical colour systems, has developed over thousands of years of recorded history. Different ways of identifying and classifying colours have been theorised since ancient times. More recently, scientifically accurate means of measuring the visible light spectrum have been developed.

Today, many of us are still taught as children that red, yellow and blue are **primary colours,** and we learn to mix paints and crayons using this principle from a very early age**.** While this traditional colour system credited to Sir Isaac Newton (see Figure 1.2) is good for some practical colour mixing methods, it isn't scientifically accurate, based on what we now know about light and colour. It's useful to learn how colour theory has developed over time, beyond mixing paint pigments, if you are working with colour in any field, whether creative or scientific.

This part of Chapter 1 contains a brief history of colour theories from a selection of philosophers, scholars, scientists and artists who have made significant contributions to this field.

**Timeline of discoveries:**

- **Antiquity (c. 500 BCE to 300 CE)**
- **Middle Ages and Renaissance (c. 400 to 1600 CE)**
- **The Enlightenment (c. 1650 to 1800)**
- **Modern era (c. 1850 to 1980)**
- **Contemporary Colour Systems (c. 1930 – 2020+)**

# Antiquity (c. 500 BCE to 300 CE)

## Ancient philosophy and theories of colour vision



Figure 1.3. Depiction of Plato's Academy. Image attribution: Unknown author, Plato's Academy mosaic from Pompeii, marked as public domain, on Wikimedia Commons

Ancient Greek philosophers such as Democritus, Plato (See Figure 1.3) and Aristotle devised theories of colour based on the teachings of Pythagoras and theories of music, maths, astronomy, and universal harmony. The four colours of white, black, red and yellow were popular as the basic and elemental colours used in much of ancient Greek artwork – perhaps because of the plentiful earthy pigments (ochres) that were used at the time.

Democritus theorised about energy and the characteristics of atoms in an object which created visible colours. Plato thought that the eye transmitted rays of vision towards an object (fire rays placed in our eyes by the gods), which also self-radiated rays of colour.

Aristotle, however, rejected theories of the eye radiating rays of vision because if that were true, he argued, we would have the ability to see at night. Aristotle's colour system included seven primary colours: white, black, red (crimson), yellow, violet, green and blue.

Ptolemy (Claudius Ptolemaeus), an ancient astronomer, geographer, and mathematician, considered the Earth the centre of the universe (the "Ptolemaic system"). He experimented with **optics** and light refraction, and believed that the eye generates rays which send back information about colour, shape, size and distance.

# Middle Ages and Renaissance (c. 400 to 1600 CE)

## The Islamic Golden Age: optics and colour systems



Figure 1.4. Engraving from the title page of Opticae Thesaurus. Image attribution: Opticae Thesaurus, a latin edition of Ibn al-Haytham's Book of Optics. Among other things it shows how Archimedes allegedly set Roman ships on fire with parabolic mirrors during the Siege of Syracuse. Unknown illustrator, Thesaurus opticus Titelblatt, marked as public domain, more details on Wikimedia Commons

During the **Islamic Golden Age** ($8^{th}$ to $14^{th}$ centuries), Arabic Islamic scholars moved away from the theories of Aristotle and Ptolemy to make their own discoveries in colour theory. Between the years 800 – 1200 CE, scholars such as **al-Kindi**, **Ibn al-Haythem** (Alhazen) and **Ibn Rushd** (Averroes), concluded that light was necessary for seeing colours – not rays from the eyes.

**Ibn al-Haythem** (known as the father of modern optics – Figure 1.4) experimented with light and glass spheres of water, observing a rainbow spectrum – the bending (refraction) of light rays into different colours. He noted that red light rays bent the least, and blue light rays bent the most. The scholar Nishaburi proposed the beginnings of a hue scale for describing colour in a system.
Ibn al-Haythem, *Book of Optics*, c. 1011 CE

## The Middle Ages: Grosseteste's colour system



Figure 1.5. c, eyes crossed, seated with miter and crozier, his right hand raised in blessing. Image attribution: Unknown 14th century scribe, Grosseteste bishop, marked as public domain, on Wikimedia Commons

Around 1200 CE, the scholar **Robert Grosseteste** (Bishop of Lincoln and, it is speculated, the first chancellor of Oxford University – Figure 1.5) developed a colour system of seven colours. Although we don't know what those colours were, he may have been the first to separate chromatic colours (red, green, blue, yellow) from achromatic colours (black, grey, and white) in a colour system.

## The Renaissance: colour primaries and colour wheels

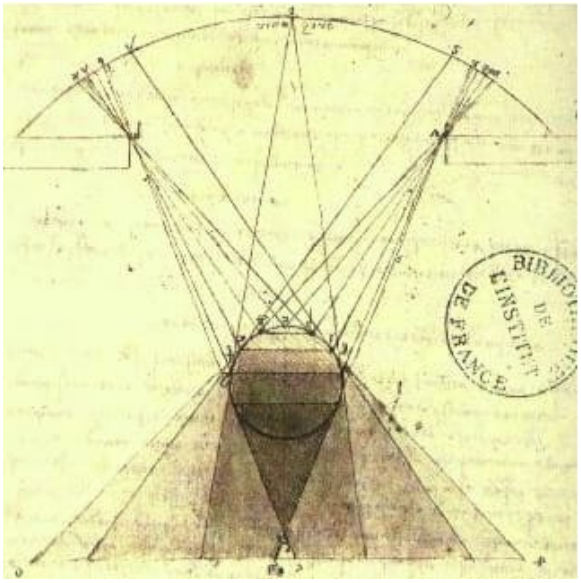


Figure 1.6 Da Vinci's study of the gradation of shadows on spheres. Image attribution: Leonardo da Vinci, Study of the Graduations of Shadows on Spheres, marked as public domain, on Wikimedia Commons

**Leon Battista Alberti** and **Leonardo da Vinci** were Italian Renaissance artists and **polymaths** who both had an interest in colour theory from a practical perspective (circa 1450 to 1500 CE). They wanted to understand colour to better mix pigments for painting artworks. Alberti recognised four colours (yellow, green, blue, red) – although he found yellow to be a problematic colour and sometimes replaced it with grey in his four-colour square. Da Vinci investigated the complexities of colour, light and physical materials such as pigments (Figure 1.6). He listed six colours as his basic primaries (white, yellow, green, blue, red, black).

He included green in his primaries although he recognised that green could be mixed from yellow and blue making it also a secondary colour.

**Aron Sigfrid Forsius** – a Finnish astronomer, documented his theory on the colour values Hue, Saturation and Value in 1611.

The physician and mystic **Robert Fludd** is credited with developing the first colour wheel based on Aristotle's theories of colour around 1629 to 1631.

# The Enlightenment (c. 1650 to 1800)

## Newton: the rainbow spectrum and optics

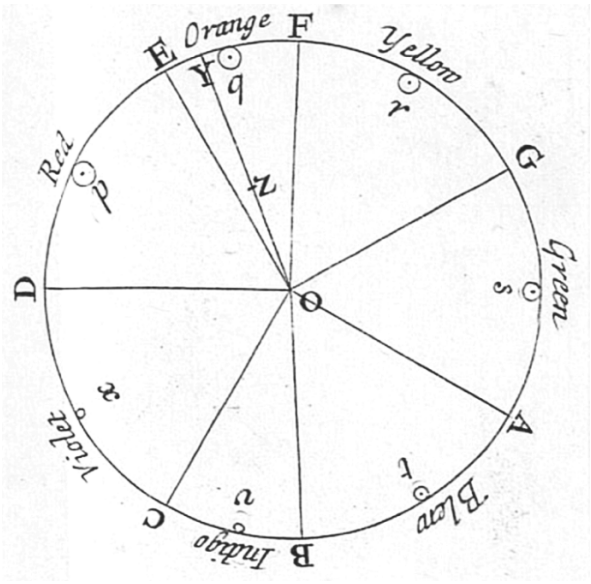



Figure 1.7. Newton's colour circle from his publication Opticks. Image attribution: Isaac Newton, Newton's color circle, from Opticks. 1704, from Book I, Part II, Proposition VI, Problem 2. Marked as public domain, on Wikimedia Commons

**Sir Isaac Newton** is credited with developing the first colour wheel in 1672 (Figure 1.7) based on colour hue relationships. He identified the **rainbow spectrum** through his experiments with light and prisms. His work led to many breakthroughs in optics, physics and chemistry. Newton's publication ***Opticks*** (Figure 1.8) is recognised as one of the great works of science. It documents Newton's discoveries in identifying the visible spectrum and the colours ROYGBIV (Red, Orange, Yellow, Green, Blue, Indigo, Violet). See PART 2- The Visible Spectrum" data-cke-saved-href="/Courses/Coalinga_College/Color_Theory_and_Applications/02:_PART_2-__The_Visible_Spectrum" href="/Courses/Coalinga_College/Color_Theory_and_Applications/02:_PART_2-__The_Visible_Spectrum" data-quail-id="153">Chapter 2 – Colour theory: the visible spectrum for details about this theory.
Link to the Gutenberg Ebook of Opticks

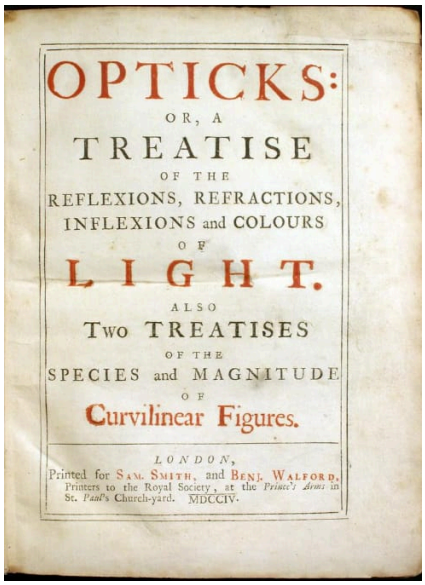



Figure 1.8. Image attribution: Isaac Newton, Opticks, marked as public domain, on Wikimedia Commons

## Goethe and Schopenhauer: perceptual colour and colour aesthetics

**Johann Wolfgang von Goethe** (poet and artist), published his ***Theory of Colors*** in 1810 (Figure 1.9). He was dismissed by many, perhaps because he refuted Newton's theories of colour by suggesting that colour was subjectively experienced. He thought that darkness was an important part of the colour spectrum. His explorations of the psychological impact of colour on mood is considered the earliest systematic study of this kind.

His work influenced artists like J.M.W. Turner (Painting *Light and Colour (Goethe's Theory)- the Morning after the Deluge. Moses writing the Book of Genesis* 1943). View this painting on The Tate gallery website: [The Tate: Joseph Mallord William Turner, Light and Colour (Goethe's Theory) – the Morning after the Deluge – Moses Writing the Book of Genesis]

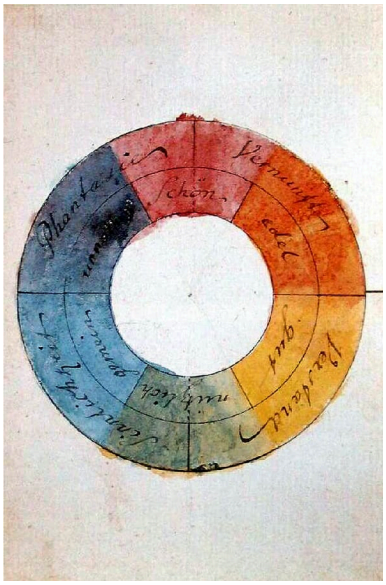


Figure 1.9. Goethe's colour wheel. Image attribution: The original uploader was Luestling at German Wikipedia, Goethe, Farbenkreis zur Symbolisierung des menschlichen Geistes- und Seelenlebens, 1809, marked as public domain, on Wikimedia Commons

The German philosopher **Arthur Schopenhauer** wrote his book ***On Vision and Colours,*** which was heavily influenced by his discussions with Goethe. Despite theoretical differences, they were both interested in physiological perception of colour.

**Johannes Itten** based his work with colour on these theories (see 1.3 Colour Aesthetics for more about Itten).

Learn more here:

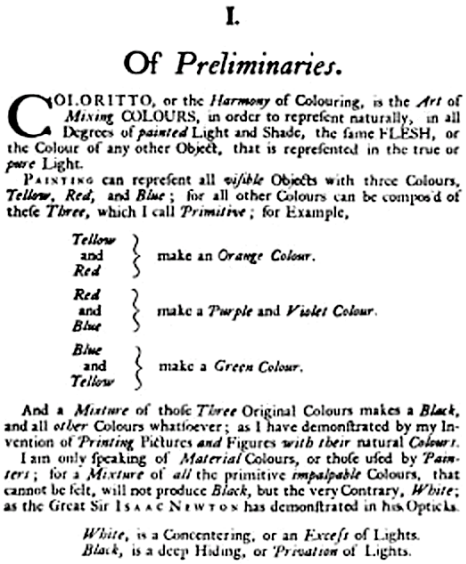
- The Marginalia – Goethe: Theory of Colour
- Smithsonian Libraries: The Science of Colour

## Le Blon: the first three-colour printing method

**Jacob Christoph Le Blon** (a.k.a. Jakob Christoffel Le Blon) was the first to devise a three-colour printing method in 1710, using the traditional primary colours Red, Yellow and Blue (Figure 1.10). This formed the basis for our CMYK colour printing system today. He used the printing method of *Mezzotint* to create three or four engraved plates, each with a different colour, which allowed for making prints with a wide range of colours.

See his book on Archive.org: *Coloritto, or, The harmony of colouring in painting : reduced to mechanical practice, under easy precepts and infallible rules, together with some colour'd figures, in order to render the said precepts and rules intelligible not only to painters, but even to all lovers of painting:*

### Archive.org: Coloritto



I.

Of *Preliminaries.*

COLORITTO, or the *Harmony* of Colouring, is the *Art* of *Mixing* COLOURS, in order to repreſent naturally, in all Degrees of *painted* Light and Shade, the ſame FLESH, or the Colour of any other Object, that is repreſented in the true or *pure* Light.

PAINTING can repreſent all *viſible* Objects with three Colours, *Yellow*, *Red*, and *Blue*; for all other Colours can be compos'd of theſe *Three*, which I call *Primitive*; for Example,

*Yellow* and *Red* } make an *Orange Colour.*

*Red* and *Blue* } make a *Purple* and *Violet Colour.*

*Blue* and *Yellow* } make a *Green Colour.*

And a *Mixture* of thoſe *Three* Original Colours makes a *Black*, and all *other* Colours whatſoever; as I have demonſtrated by my Invention of *Printing* Pictures *and* Figures *with their* natural *Colours*.

I am only ſpeaking of *Material* Colours, or thoſe uſed by *Painters*; for a *Mixture* of *all* the primitive *impalpable* Colours, that cannot be felt, will not produce *Black*, but the very Contrary, *White*; as the Great Sir ISAAC NEWTON has demonſtrated in his Opticks.

*White*, is a Concentering, or an *Exceſs* of Lights.
*Black*, is a deep Hiding, or *Privation* of Lights.

Figure 1.10. Three-colour printing by Le Blon. Image attribution: Jacob Christoph Le Blon, Le Blon three-color printing, marked as public domain, on Wikimedia Commons

# Modern era (c. 1850 to 1980)




Figure 1.11. Chevrel's chromatic circle. Image attribution: Michel Chevreul, Cercle chromatique Chevreul 3, image marked as public domain, on Wikimedia Commons. Select images to enlarge.

## Chevreul: 72-colour wheel and perceptual colour

Chevrel's <span class=
RYB chromatic diagram" class="internal default" data-cke-saved-src="/@api/deki/files/199095/Screenshot_2026-06-03_102213.png" src="/@api/deki/files/199095/Screenshot_2026-06-03_102213.png" data-quail-id="218">

Figure 1.12. Chevrel's RYB chromatic diagram. Image attribution: Benjamin Stillman after Chevreul, Chevreul's RYB chromatic diagram, image marked as public domain, on Wikimedia Commons. Select images to enlarge

The chemist **Michel Eugène Chevreul** devised a **72-colour wheel** in 1839 (Figures 1.11 and 1.12) which not only showed primary colours, but also showed secondary and tertiary colours, and different brightness levels. He experimented with dyes for carpet manufacture, and through this work, identified the relationships of colours when placed next to each other, and how our perception of colour is relational. His work in the field of optics and the way the human brain interprets colour had an important influence on many art movements, including **Impressionism** and **Orphic Cubism**.

## Maxwell: RGB primaries and the first colour photograph

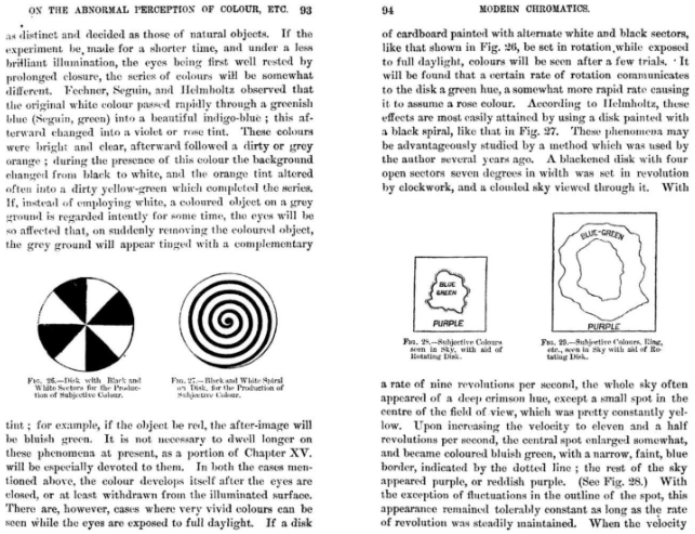


Figure 1.13. Maxwell's three-colour photograph – possibly the first colour photograph. Image attribution: The first color photograph made by the three-color method suggested by James Clerk Maxwell in 1855, taken in 1861 by Thomas Sutton. The subject is a colored ribbon, usually described as a tartan ribbon, on Wikimedia Commons

Physicist **James Clerk Maxwell** was the first to suggest that red, green and blue make better primary colours than red, yellow and blue (based on Newton's theory of the visible spectrum and that red, green and blue light can be used to make all other colours). He also explored colour blindness in his research.

His paper **"**On the theory of compound colours, and the relations of the colors of the spectrum"[1] in 1860, is recognised as an important contribution to colour theory. He may have also been the first person to take a colour photograph of an object in 1861 (Figure 1.13) by projecting three negatives with red, green and blue coloured lights – as shown in Figure 13.

## Rood: perceptual colour blending and the Impressionists



ON THE ABNORMAL PERCEPTION OF COLOUR, ETC. 93

as distinct and decided as those of natural objects. If the experiment be made for a shorter time, and under a less brilliant illumination, the eyes being first well rested by prolonged closure, the series of colours will be somewhat different. Fechner, Seguin, and Helmholtz observed that the original white colour passed rapidly through a greenish blue (Seguin, green) into a beautiful indigo-blue; this afterward changed into a violet or rose tint. These colours were bright and clear, afterward followed a dirty or grey orange; during the presence of this colour the background changed from black to white, and the orange tint altered often into a dirty yellow-green which completed the series. If, instead of employing white, a coloured object on a grey ground is regarded intently for some time, the eyes will be so affected that, on suddenly removing the coloured object, the grey ground will appear tinged with a complementary

FIG. 26.—Disk with Black and White Sectors for the Production of Subjective Colour.

FIG. 27.—Black and White Spiral on Disk, for the Production of Subjective Colour.

tint; for example, if the object be red, the after-image will be bluish green. It is not necessary to dwell longer on these phenomena at present, as a portion of Chapter XV. will be especially devoted to them. In both the cases mentioned above, the colour develops itself after the eyes are closed, or at least withdrawn from the illuminated surface. There are, however, cases where very vivid colours can be seen while the eyes are exposed to full daylight. If a disk

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of cardboard painted with alternate white and black sectors, like that shown in Fig. 26, be set in rotation while exposed to full daylight, colours will be seen after a few trials. It will be found that a certain rate of rotation communicates to the disk a green hue, a somewhat more rapid rate causing it to assume a rose colour. According to Helmholtz, these effects are most easily attained by using a disk painted with a black spiral, like that in Fig. 27. These phenomena may be advantageously studied by a method which was used by the author several years ago. A blackened disk with four open sectors seven degrees in width was set in revolution by clockwork, and a clouded sky viewed through it. With



FIG. 28.—Subjective Colours seen in Sky, with aid of Rotating Disk.

FIG. 29.—Subjective Colours, Ring, etc., seen in Sky with aid of Rotating Disk.

a rate of nine revolutions per second, the whole sky often appeared of a deep crimson hue, except a small spot in the centre of the field of view, which was pretty constantly yellow. Upon increasing the velocity to eleven and a half revolutions per second, the central spot enlarged somewhat, and became coloured bluish green, with a narrow, faint, blue border, indicated by the dotted line; the rest of the sky appeared purple, or reddish purple. (See Fig. 28.) With the exception of fluctuations in the outline of the spot, this appearance remained tolerably constant as long as the rate of revolution was steadily maintained. When the velocity

Figure 1.14. Pages from Rood's publication Modern Chromatics With Applications to Art and Industry. Image attribution: Image capture from Modern Chromatics With Applications to Art And Industry by Ogden N. Rood on Archive.org

**Ogden Nicholas Rood**, a physicist, divided colour into three constants: purity, luminosity and hue – similar to Maxwell's properties of colour. He also developed a theory of contrasting and complementary colours – suggesting that small lines or dots of different colours, when viewed from a distance, blend into a new colour. This work had a great influence on the Impressionist pointillist painters like **Georges-Pierre Seurat**. Rood published ***Modern Chromatics, with Applications to Art and Industry***[2], in 1879 (Figure 1.14).

## The Munsell colour system

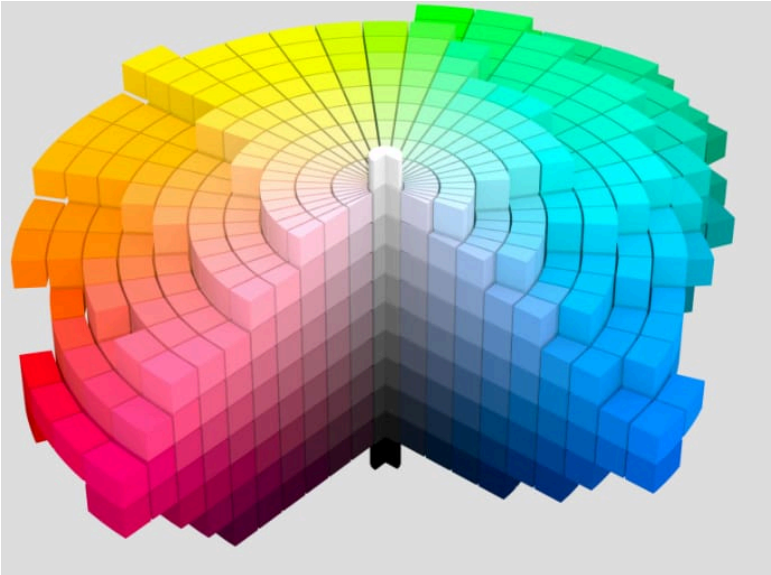


Figure 1.15. Munsell's Colour solid cylindrical coordinates – grey. Image attribution: Munsell 1943 color solid cylindrical coordinates.png: SharkD derivative work: Datumizer, Munsell 1943 color solid cylindrical coordinates gray, CC BY-SA 3.0, on Wikimedia Commons

**Albert Henry Munsell** (an artist and art teacher) developed the **Munsell color system** in 1915. It is still one of the most-used colour systems – especially in design. His colour system is said to span art and science due to the numbering system he developed to classify colour, which is rigorous enough for scientific use, but also simple enough for artists or those with no scientific background to understand. His system is associated with the word "chroma", which is the saturation or intensity of hue.

Learn more about the *Munsell Color System* and *Munsell Color* company in this publication on Project Gutenberg: *A Color Notation* by A.H. Munsell, 1905

## Ostwald: colour aesthetics, the Bauhaus and De Stijl



Figure 1.16. Oswald's colour system – photograph of physical model. Image attribution: Photograph of Ostwald's colour system, licenced under GNU Free Documentation License, on Wikimedia Commons

**Wilhelm Ostwald** (a Nobel prize winner in Chemistry), explored colour harmonies and why some colours look pleasant when placed together and others look unpleasant. He attempted to find a scientific theory for colour harmony – ***The Colour Primer*** 1916/1917 was the most notable publication he produced. His perceptual colour system (Figure 1.16) was different to Munsell's in that he identified *Colour-content*, *White-content* and *Black-content*. Ostwald was associated with the **Bauhaus** and while his theories did not gain the same popularity or acceptance as Munsell's, his work influenced many artists such as **Piet Mondrian**, and other artists of the **de Stijl** group[3].

# Contemporary Colour Systems (c. 1930 – 2020+)

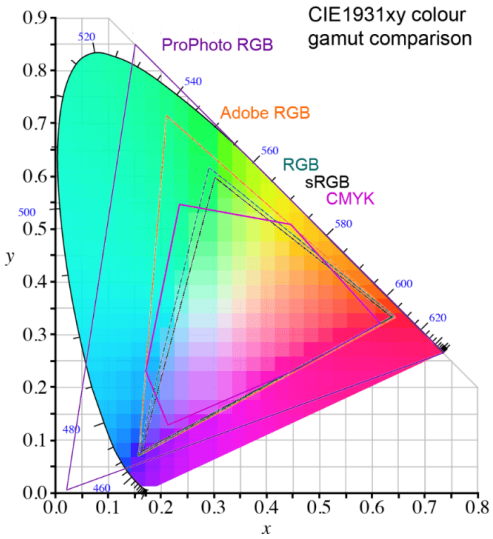



Figure 1.17. CIE1931xy gamut comparison diagram. Image attribution: BenRG and cmglee, CIE1931xy gamut comparison, text label modifications by Lisa Cianci, 2022, CC BY-SA 3.0, on Wikimedia Commons

## CIE 1931 colour spaces

CIE stands for "*Commission Internationale de l'Eclairage*" in French, which in English is the "*International Commission on Illumination*". This organisation, founded in 1931, is the international authority on light, illumination, colour, and colour spaces.

The CIE 1931 colour spaces made the first clearly defined links between wavelengths in the visible spectrum and colour vision in humans. The development of this colour space became the standard tool for colour management in printing, digital displays and cameras. The two colour spaces – **CIE 1931 RGB** and **CIE 1931 XYZ** – were developed from a series of experiments in the late 1920s by William David Wright and John Guild.

These colour spaces and others, such as the CIELUV 1976 colour space, are still widely used. Figure 17 shows the CIE 1931 xy colour space and other colour space gamuts within CIE. As you can see in Figure 1.17, CMYK has a smaller gamut than the various RGB colour spaces – which can affect colour conversion for printing. See 3.3 Colour systems: printing in this resource for more information on colour spaces and conversion to CMYK.

## CIELAB colour space

**CIELAB colour space** – also referred to as **CIE L*a*b** – is a colour space defined by the **International Commission on Illumination** (CIE) in 1976. Its three colour values are **L** – perceptual lightness, and **a/b** for what was thought to be at the time, the four unique colours of human vision: red, green, blue and yellow.

- a = red/green scale
- b = blue/yellow scale

**CIELAB** is intended to represent a perceptual colour space – what the human eye can see – i.e. a *human colour gamut*. LAB colour is a device-independent colour space that doesn't relate to any particular technology like a computer, television or printer. This differs from colour systems like RGB or CMYK, which are dependent on specific devices or applications. Because CIELAB has a wider gamut than other colour spaces, it is a useful system for detecting small variations in colour, although depending on the limitations of your device to display or print colour, not all LAB colours may be accurately visually represented.

We often see CIELAB colour space represented as a 2-dimensional graph as in Figure 1.17, however, the best representation is in 3-dimensions, as shown in Figure 1.18.

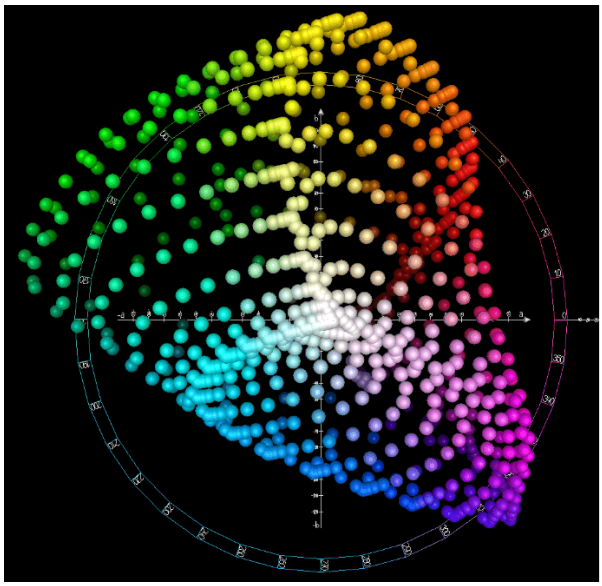


Figure 1.18. CIELAB colour space – 3-dimensional model. Image attribution: Holger kkk Everding, CIELAB color space top view, CC BY-SA 4.0, on Wikimedia Commons

# Test yourself: history of colour theories

## A multiple choice quiz to test your understanding of the history of colour theories

## (5 minutes or less)

### How did you go?

If you need to learn more about this topic, you can read this section again.

# References and resources: history of colour theories

Here are some useful links to library subject guide resources and other online resources to further your research.

- RMIT Library: Interior design subject guide
- For more detailed history of colour theory and systems, visit this informative guide to *Colour order systems in art and science* by Prof. Narciso Silvestrini and Prof. Ernst Peter Fischer.
- Also see the *Routledge handbook of Philosophy of Colour* for a more academic approach to colour theory.

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# 1.3: Cultural Interpretations



Figure 1.19. Coloured powders used in the Indian Holi festival. Image by Rahulrk07 via Wikimedia Commons, licensed under CC BY-SA 4.0.

Scientific theories of colour cross geographic borders and are described as 'universal', but meanings and symbolism attached to colour can be very specific to different cultural groups around the world, such as the Indian Holi festival of colour">[1] (Figure 1.19), and at different times throughout human history. Despite these culturally specific meanings and symbolism, studies investigating emotional links to colour have found some links to be shared around the world.

If you are an artist or designer of products, packaging, fashion, interior/exterior environments, digital media, games, etc., understanding how colour can affect your audience is useful.

**Topics covered**

This chapter will include a brief introduction to cultural interpretations of colour and where colour has been linked to human emotion, psychology and physiology.

- Colour psychology and physiology
- Colour symbolism in different cultures
- Colour and language

## Colour psychology and physiology

It is generally accepted that colour can affect our emotions and mood. Different colours have been identified as triggering certain emotional or physical reactions. Colours can have both positive and negative associations and these can vary for each person.

### Are emotional links to colour universal?

Recent studies investigating emotional links to colour have found that although our perceptions and uses of colour can be specific to different cultural groups, some links are shared universally">[1].

**This page provides some background into theories of colour and its effect on human psychology and physiology. Topics covered:**

- Colour associations
- Colour in advertising and logo design
- Colour, psychology and art therapy
- Colour and medical therapy

## Colour associations

You might have your own colour associations like these listed in Table 1.1 – can you think of any more emotions or states to add to these colours that have meaning for you?

*Colour associations*

| Colour | Meaning |
|---|---|
| Red | heat, activity, anger, danger, passion, energy |
| Purple | wisdom, power, imagination, spirituality, royalty, sophistication, mystery |
| Pink | love, affection, romance, softness, kindness, sweetness |
| White | purity, cleanliness, innocence, perfection, spirituality |
| Yellow | happiness, warmth, positivity, cheerfulness, compassion |
| Orange | warning, warmth, fun, youth, optimism, excitement |
| Gold | wealth, fortune, luxury, triumph, royalty, abundance, glamour |
| Black | elegance, drama, power, death, evil |
| Blue | cold/coolness, stability, loyalty, seriousness, envy, trust, peace |
| Green | calm, serenity, relaxation, renewal, envy, wealth, abundance |
| Brown | practicality, honesty, simplicity, dependability, trustworthiness |
| Grey | stability, authority, maturity, modernity, the mundane, sadness, boredo |

View this infographic on the *Information is Beautiful* website for more colour associations.

## Colour in advertising and logo design

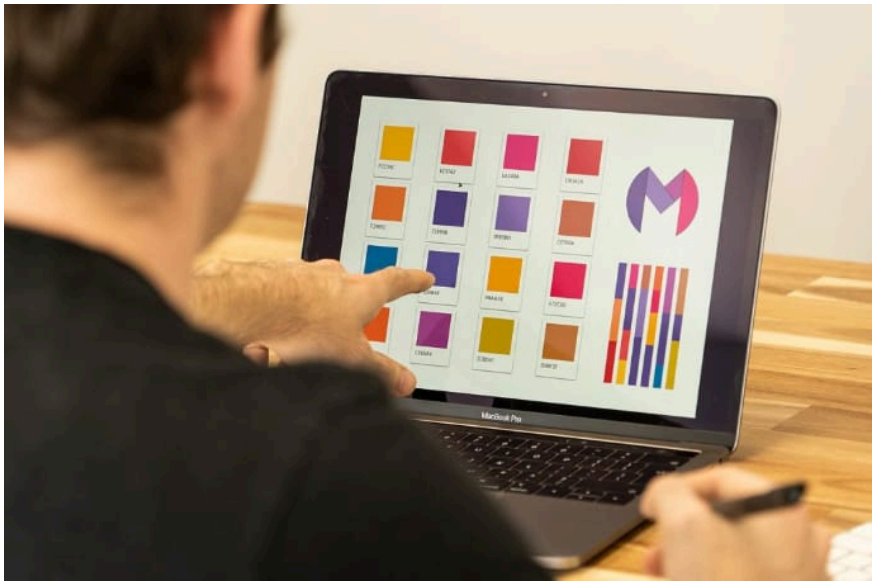


Figure 1.20. Logo Design. Image attribution: Claireneon, Colour palette selection for logo design, CC BY-SA 4.0

Many studies and articles you will find online about how colours affect our emotions and mood are ***anecdotal*** – that means they are not based on reliable research or factual evidence. However, there is significant evidence in marketing research that colour plays an important role in what we buy and how we are attracted to different products.

For example, it's no coincidence that popular fast-food companies like McDonald's or Hungry Jack's have red and yellow logos and packaging designs – these colours are said to stimulate appetite.

Other well-known colours in advertising include Coca-Cola red, Facebook blue, Cadbury purple, Fanta orange, Android green, and Barbie pink. These colours have become iconic in contemporary culture, and it is easy to associate the colour with the product. See Figure 1.20 for some examples of well-known logo designs arranged by colour. Do you notice any patterns? Do certain types of businesses prefer certain colours?

Learn more about the psychology of colour in marketing.

### Logo design

Colour in logo design can be used to communicate meaning about a particular brand or product and what an organisation/individual represents or how they want their customers to perceive them. Some logos may have different colour versions depending on usage, many iconic logos use consistent colour and have strict rules about usage. For example, have you ever seen a green Coca-Cola can with pink text? Probably not!

If you are designing a logo for yourself or a client, you may need to create a ***style guide*** or ***brand guide*** which is a way of controlling and communicating how your logo and other graphics must be used. Colour information is very important in a style guide. You should include information about the colours that can be used in the logo and background, how much space should be around the logo, the relative size and scale of the logo, and where it can be positioned on printed or screen media.

For example, Google's Material Design colour system (Figures 1.21 and 1.22) give very clear instructions for the correct ways to develop colour schemes and palettes that work with branding to create well-designed and accessible interfaces for screen devices.

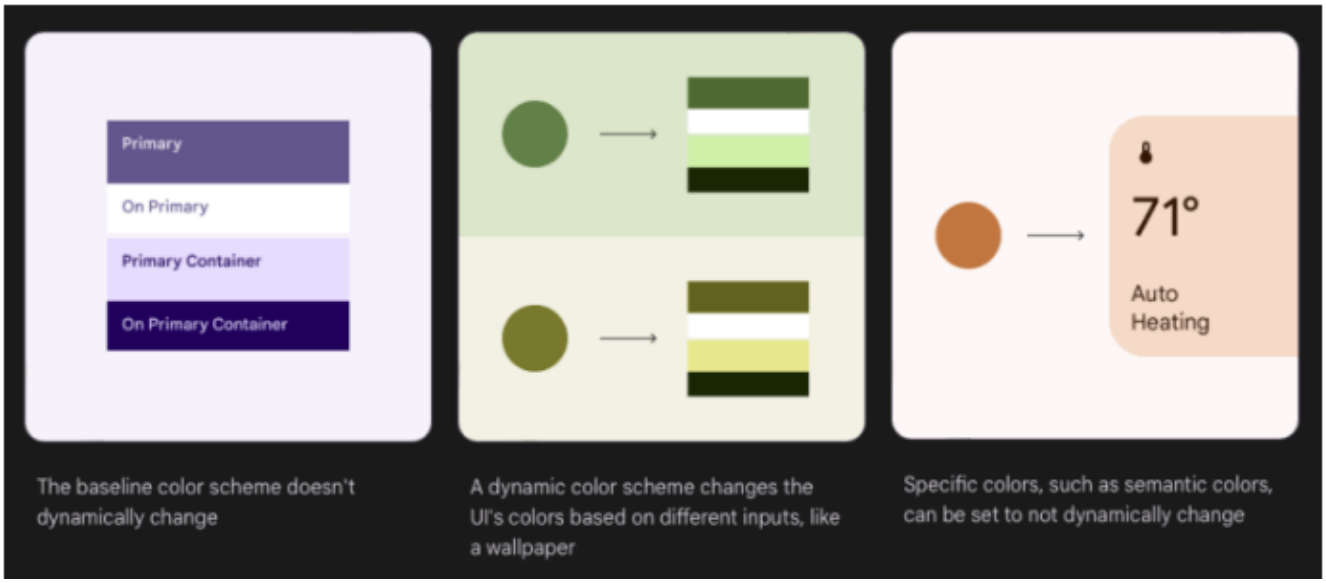



Figure 1.21 Google Material Design – examples of colour usage. Image attribution Google Material Design, Apache licence 2.0. Select images to enlarge

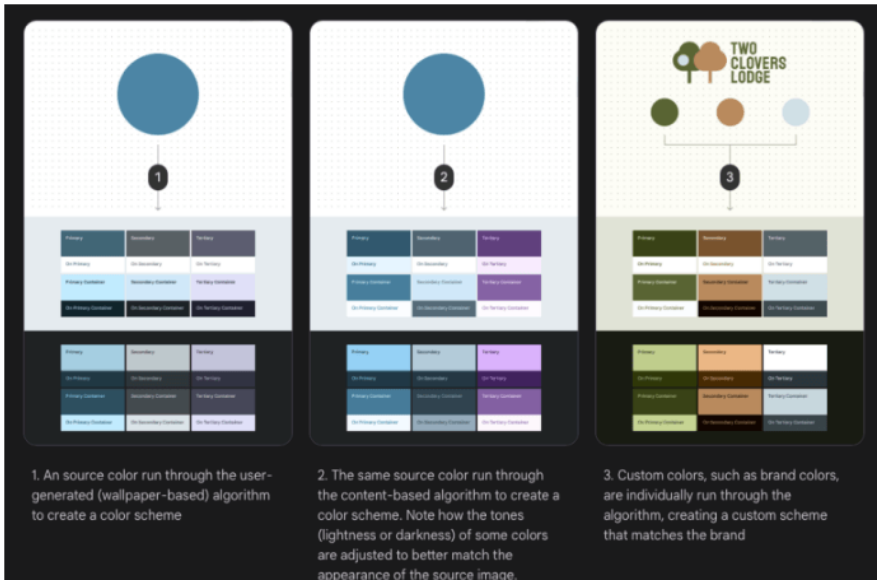



Figure 1.22. Google Material Design – examples of colour usage. Image attribution Google Material Design , Apache licence 2.0 . Select images to enlarge.

Learn more about colour and logos from these online resources:

- Color psychology: the logo color tricks used by top companies
- Exciting red and competent blue – the importance of color in marketing
- The colour emotion guide
- Psychology of colour in logo design

## Colour, psychology and art therapy

### Colour, personality and pseudoscience

Colour has also historically been linked to human psychological traits and personality types, although these theories are now outdated and have no basis in current psychology. One of the better-known examples of this is from the work of **Carl Jung** who was a Swiss psychiatrist and psychoanalyst in the early 20th century. He is quoted as saying "colours are the mother tongue of the subconscious" and "colours express the main psychic functions of man".

Although greatly influenced by Sigmund Freud (the founder of Psychoanalysis), Jung did not agree with all of Freud's theories. He founded **Analytical Psychology** in 1913 after breaking with Freud. One of Jung's theories was the classification of psychological personality types linked to four colours: red, blue, green and yellow. These colours were placed in a grid with **X** and **Y** axes.

- **X** represents the line between *Introversion* and *Extroversion*,
- **Y** represents the line between *Thinking* and *Feeling*.

This theoretical way of determining a person's psychological type is now dismissed by today's psychologists as it's not based on any proven evidence of how our brains work. Personality is far more complex than Jung's limited classification system can describe – which Jung also acknowledged himself.

However, Jung's book ***Psychological Types (1921)*** was further developed in the 1940s by **Katherine Cook Briggs** and her daughter **Isabel Briggs Myer** (neither had formal training in psychology) into the **Myers-Briggs 16 personality types,** which also has colour associations and is a popular personality test that is still used today. It is important to note that there is no evidence that the Myers-Briggs personality test is an accurate or useful tool for determining a person's personality, or success in career or life choices.

## Art Therapy

Where Jung's theories about colour and creativity have found greater practical use is in the emergence of **art therapy** as a field of practice that helps people deal with trauma and illness through creative work. Colour can be used effectively in art therapy as part of a process of expressing troublesome thoughts and feelings in a visual way.

Learn more from these online resources:

- What color psychology really means
- What is Art Therapy?
- Hogan, Susan. *Healing arts : the history of art therapy,* London: Jessica Kingsley, 2001.
- Hogan, Susan ed. *Feminist Approaches to Art Therapy, Routledge 1997*
- More publications by Susan Hogan on Art Therapy
- Why the Myers-Briggs test is totally meaningless

## Colour and medical therapy

## Chromotherapy – therapy or quackery?

> It is important to note that chromotherapy (colour therapy) has been scientifically rejected due to a lack of evidence. It is regarded by the medical field as fraudulent and not having any measurable value. It is mentioned here from a historic perspective only.

Light and colour have been used in many attempts at healing therapy since ancient times. There is evidence from Ancient Egypt, Greece and India of sunlight, coloured light and coloured materials claimed to be used for healing. The Persian scholar and philosopher Ib Sina (Avicenna)(c. 970–1037 CE) also promoted the idea of using colour for healing.

These practices formed the basis for later theories of chromotherapy by practitioners such as American physician Edwin D.

Babbitt who developed a range of light therapies including a *thermolume* – a cabinet that was able to project coloured light onto various parts of the body. He also 'irradiated' water with sunlight filtered through coloured lenses. Dinshah Ghadiali was another inventor who claimed that colour therapy was the key to health. He invented a box with a 1000-watt light and coloured filters called a *Spectro-Chrome* which he claimed was able to produce twelve different colours to be used for different therapeutic purposes. He was labelled a fraud by the medical establishment of the day.



Figure 1.23. Image attribution Skin58, Blue Light acne phototherapy iClear, on Wikimedia Commons, CC BY-SA 4.0

**Phototherapy today**

Despite the debunking of these claimed 'alternative' therapies, there has been a recent rise in light therapy with the use of coloured LED lights for treatment of skin conditions such as acne or aging skin (Figure 1.23). The theory is that certain wavelengths of colour can promote healing and skin regeneration. Research in this area is recent and largely inconclusive. There are also concerns that incorrect use of these devices which have strong LED lights, may cause eye damage.

There is a type of evidence-based light therapy (phototherapy) for babies that may have **Newborn Jaundice** (*Hyperbilirubinemia*). These newborns are placed under a blue light (420–470 nm wavelengths) to treat the condition (Figure 1.24). The blue light helps to remove bilirubin from the blood. This kind of phototherapy has been used for many decades.




Figure 1.24. Newborn Jaundice treatment with a “Bili-lite”. Image attribution: User Jeremykemp on Wikipedia, Bili light with newborn, marked as public domain, on Wikimedia Commons

Learn more from these online publications:

- Edwin D Babbitt, *The Principals of Light and Colour* 1878, Babbitt and Co.
- Quackwatch.org “Colourful Nonsense: Dinshah Gladioli and his Spectro-Chrome Device”
- *Harvard Health Publishing*, Harvard Medical School, 2019, “LED lights: are they a cure for your skin woes?”

1. Mohr, C., & Jonauskaite, D. (2022, February 8). Why links between colors and emotions may be universal … And the enduring debate over the meaning of red [Journal]. Psychology Today. < psychologytoday.com [www.psychologytoday.com] >

## Colour symbolism in different cultures

Symbolic colour meanings have been associated in art and *anthropology* with different cultural, spiritual or religious groups throughout our recorded history. In many ancient cultures, colour symbolism was related to the natural elements – earth, water, fire, air, etc.

For example, traditional Chinese colour symbolism associates the elements and primary colours shown in Table 1.2.

*Colour symbolism in different cultures*

| Colour sample | Definition |
|---|---|
| | Red (Zhusha Hong) = fire |
| | Yellow (Ming Huang) = earth |
| | White (Chun Bai) = metal |
| | Black (Xuan Se) = water |
| | Blue (Qing Se) = wood |

In other cultures, certain colours that were made from rare pigments were highly prized and thus came to have symbolic meaning. Here are two examples:

## Tyrian purple

In ancient Roman culture, purple (Tyrian purple or Phoenecian red/purple) was a special colour reserved for the clothing of emperors and senators. This was because the vibrant purple dye was made from a particular species of sea snail (Murex or Muricidae) and it was expensive and very difficult to create.



Figure 1.25. Minerva as the goddess Roma. Image attribution: Dennis Jarvis from Halifax, Canada, Italy-0540 – Dress is not painted.... (5168496402), on Wikimedia Commons, CC BY-SA 2.0

Deep red porphyry from Egypt (Imperial Porphyry) is an igneous rock that was also valued by the Romans because it was very close to Tyrian purple in colour. Figure 1.25, shows a statue of Minerva (as Goddess Roma) from Capitol Square in Rome (c 300 CE). Her dress is made from red porphyry to represent the Tyrian purple dye of imperial Roman clothing. (Read more about dyes in 3.4 Colour systems: pigments and dyes)

## Ultramarine (lapis lazuli)

Blue was used symbolically in Christian religious imagery during the Renaissance – partly because the blue pigment was very rare. The cloak of the Virgin Mary was often coloured with ultramarine blue (Figure 1.26). The colour blue also represented the heavens and the celestial, so it had more than one symbolic meaning in this context.




Figure 1.26. Madonna del Cardellino by Raffaello Sanzio shows the Madonna with a blue cloak painted with ultramarine pigment. Image attribution: Raphael artist QS:P170,Q5597, Raffaello Sanzio – Madonna del Cardellino – Google Art Project, marked as public domain, on Wikimedia Commons

Ultramarine pigment was made from a deep blue precious stone –lapis lazuli, said to be worth more than gold at the time. It has been claimed that Michelangelo couldn't afford enough ultramarine blue for the Virgin's cloak, and so never completed his painting *The Entombment*.

Johannes Vermeer put his family in debt to acquire the pigment for his paintings such as *The Milk Maid* (Figure 1.27).



Figure 1.27. The Milk Maid by Johannes Vermeer. Image attribution: Johannes Vermeer artist QS:P170,Q41264, Johannes Vermeer – Het melkmeisje – Google Art Project, marked as public domain, on Wikimedia Commons

## Flags of the world

In contemporary international culture, we see symbolic colour all around us in fashion, products and media. Flags of the world are also an obvious example of symbolic colour (Figure 1.28). Colours used in national flags have symbolic meanings related to a country's culture and history.



Figure 1.28. Flag-map of the world. Image attribution: Transparent 6lue, Flag-map of the world, marked as public domain, on Wikimedia Commons. Select image to enlarge.

## Australian First Nation flags

Our Australian Aboriginal flag (Figure 1.29) has three colours in a design that represents:

- the earth (red),
- the people (black), and
- the sun (yellow)



Figure 1.29. Australian Aboriginal Flag Image attribution: Aboriginal artist Harold Thomas (Vector graphics image by Trisreed), Australian Aboriginal Flag, marked as public domain, on Wikimedia Common

The **Torres Strait flag** has the following colour symbolism:

- **Green** – the mainlands (Papua New Guinea and Australia)
- **Black** – the people of the Torres Strait Islands
- **Blue** – the waters surrounding the islands

- **White** Dhari – the Dhari is a traditional headdress made and worn by men. The white colour symbolises peace.
- **White** Five-Pointed Star – the five major island groups and their ties to navigation by sea

View the Torres Strait Flag here (copyright permission to reproduce the flag must be obtained from the TSIRC).

## Pride flags

Pride flags of the LGBTIQA+ community use colours symbolically to represent various groups. There is one overarching rainbow flag for the whole community (Figure 1.30) (and a Progress Pride flag – Figure 1.31), but each subgroup also has their own flag with symbolic use of colour.



Figure 1.30. Pride flag. Image attribution: Philadelphia City Council and Tierney, Philadelphia Pride Flag, marked as public domain, more details on Wikimedia Commons

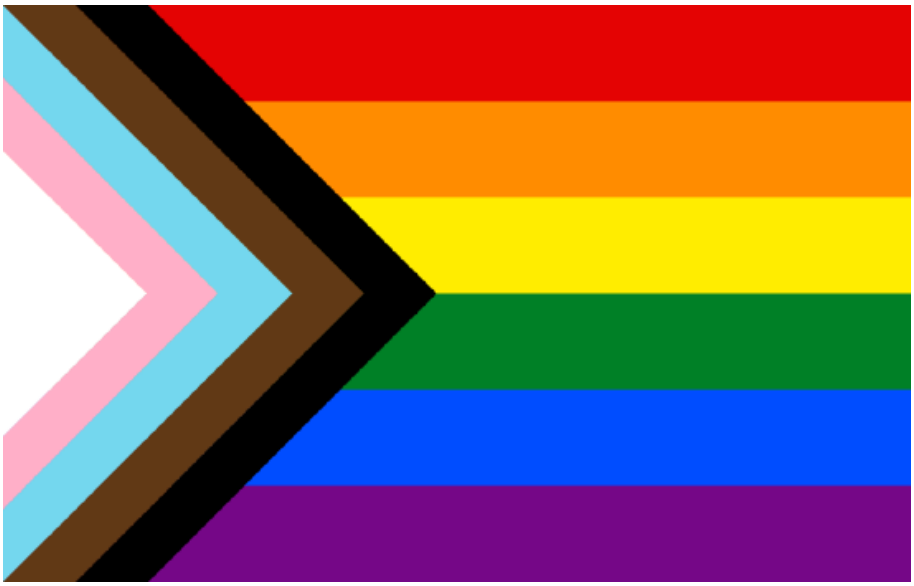


Figure 1.31. Progress pride flag. Image attribution: Paul2520, LGBTQ+ rainbow flag Quasar "Progress" variant, marked as public domain, on Wikimedia Commons

Learn more about Pride flags and colour symbolism from these online resources:

- Pride flag on Wikipedia

- Understanding color psychology though culture, symbolism, and emotion
- Color symbolism on Wikipedia
- Cross-cultural color and emotion

## Colour symbolism in Australian Indigenous culture

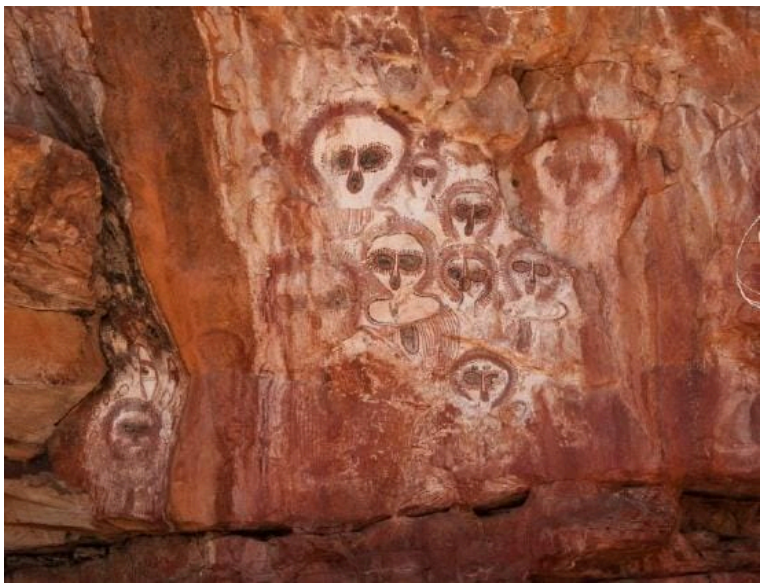


Figure 1.32. Image attribution: Aboriginal rock art in ochre colours, Graeme Churchard from Bristol (51.4414, -2.5242), UK, Aboriginal rock art on the Barnett River, Mount Elizabeth Station, on Wikimedia Commons, CC BY 2.0

Traditional Australian Aboriginal artists used the materials at hand – ochres from the ground (Figure 1.32), plants and other substances used to make dyes. Different language groups across the continent developed their own symbolic uses for colour to represent the earth, sky, animals, people, waters etc. There isn't one set of meanings that covers the whole country, and some meanings and colour making methods may be protected knowledge of certain groups.



Figure 1.33. Image attribution: Esther 1721 pixabay.com [pixabay.com], Aboriginal-art-5033444 960 720, CC0 1.0

Since European colonisation, many Indigenous artists have embraced a wider range of colours in their work – partly due to the availability of ready-made paints, or the use of digital media. In particular, since the 1970s and the beginnings of painting movements by groups in central and western Australia, materials like acrylic paints have become popular because they are

available in a variety of colours, are easy to use and quick to dry. Brighter colours have been incorporated into many Indigenous artists' practices (Figure 1.33). These colours are symbolically used to represent the intensely coloured and vibrant features of diverse landscapes across the country. Learn more about pigments and dyes in Chapter 3 – Colour systems: paint pigments and dyes

Learn more about colour in indigenous culture from these resources:

- Aboriginal Art Australia: The story of Aboriginal art
- Japingka Aboriginal Art: How Aboriginal colours and group art styles develop
- Kate Owen Gallery: Aboriginal-colours-in-art
- RMIT News: Louisa Bloomer tree artwork
- RMIT News: Mark Cleaver, Indigenous artwork Luwaytini

# Colour and language

## Naming colours



Figure 1.34. Image attribution: Homer, Odyssey manuscript. Date: 3rd quarter of the 15th century. Odyssey-crop, marked as public domain, on Wikimedia Commons

Research in the field of ***cognitive science*** over the last 150 years has included investigations into how language might influence thought and conversely, how thought might influence language. Many of the studies undertaken with different language groups around the world have analysed descriptions of colour as a way of testing these theories.

Some of this research has noted that many language groups have more descriptions for warmer colours (red, orange, purple) and less for cooler colours (blue, green, yellow).

> Some language groups like those from Papua New Guinea don't have separate words for blue and green, while others like Russian speakers have two words for blue (*siniy* [синий] – dark blue and *goluboy* [голубой] – light blue).

Studies also show that learning a new language alters your perception of colour.

It was speculated that in the past people couldn't see the colour blue because there weren't examples of words representing "blue" in ancient texts (Figure 1.34). An example of this proposition was made by politician and historian William Gladstone in his 1858 publication *Studies on Homer and the Homeric Age*[1] with regard to Homer's texts *The Iliad* and*The Odyssey*.

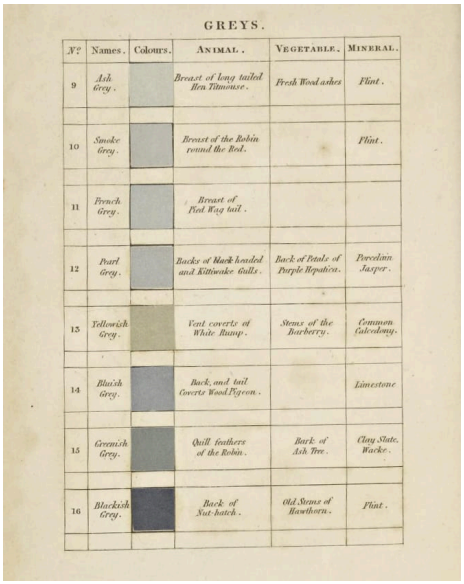
Gladstone noticed that Homer never described the sky or sea with a word that could mean “blue”, so he speculated that people from ancient times couldn’t see the same colours.

However, scientists have concluded that people from ancient times did see blue – they saw the same spectrum of colours that we can see now, but perhaps they didn’t differentiate between blue and green, or used different relational and descriptive words to describe colours like Homer’s “wine-looking sea”. It was an issue of linguistics, not optics[2].

## Colour Atlases

Around the time of **Charles Darwin**, descriptive language standards – also called ***taxonomies*** **–** for colour used by naturalists were published as ‘colour-atlases’[3] which described colours by hue and value based on natural objects such as plants, animals, and landscape features, not ‘spectral colours’ (colours such as red, blue, yellow, violet, green or orange).

Darwin was said to have a copy of such an atlas – *Werner’s Nomenclature of Colours Adapted to Zoology, Botany, Chemistry, Minerology, Anatomy and the Arts* by Patrick Syme, 1821)(Figure 1.35), during his voyage on the ***Beagle***[4] (1831-1836). This colour atlas book is still in print today.


GREYS.

| N? | Names. | Colours. | ANIMAL. | VEGETABLE. | MINERAL. |
|---|---|---|---|---|---|
| 9 | Ash Grey. | | Breast of long tailed Ben Titmouse. | Fresh Wood ashes | Flint. |
| 10 | Smoke Grey. | | Breast of the Robin round the Red. | | Flint. |
| 11 | French Grey. | | Breast of Red Wag tail. | | |
| 12 | Pearl Grey. | | Backs of Black headed and Kittiwake Gulls. | Back of Petals of Purple Hepatica. | Porcelain Jasper. |
| 13 | Yellowish Grey. | | Vent coverts of White Rump. | Stems of the Barberry. | Common Calcedony. |
| 14 | Bluish Grey. | | Back, and tail Coverts Wood Pigeon. | | Limestone |
| 15 | Greenish Grey. | | Quill feathers of the Robin. | Bark of Ash Tree. | Clay Slate, Wacke. |
| 16 | Blackish Grey. | | Back of Nut-hatch. | Old Stems of Hawthorn. | Flint. |

Figure 1.35. A page from Werner’s Nomenclature of Colours: Greys. Image attribution: Werner, Abraham Gottlob, 1749-1817; Syme, Patrick, 1774-1845, editor; Blackwood, William, 1776-1834, bookseller; Cadell, Thomas, 1773-1836, bookseller; James Ballantyne and Co., printer, Werner’s nomenclature of colours: greys, marked as public domain, on Wikimedia Commons

This method of colour classification using language standards came about because of the problem of making *spectral* colours with pigments and dyes at that time. See Chapter 3.4 Colour systems: paints and pigments for more information on pigments and dyes.

The way you think about colour may depend on your language even if we see the same spectrum of colours. Naming conventions in our language for colours may also influence how we think about colour.

If you’re an artist who uses common art materials, you might associate colour with the names of paint pigments like ‘Prussian Blue’, ‘Burnt Sienna’, ‘Alizarin Crimson’, or ‘Cadmium Yellow’. If you’re a fashion designer, you might think about colour according to popular colours used in textiles such as denim or navy blue, khaki, charcoal grey, beige or fuschia.

Today, we have seemingly endless and non-standard ways of naming colours – some of them are strange or even humorous like

these AI-generated colour names. Paint colour charts are good examples of this and they are easy to find online or in hardware stores. Descriptive language is used to classify, differentiate and market thousands of colours that have very slight variations between them.

> What colour is “Elephant’s breath”? Or “Velvet dream”?
> What’s the difference between “Natural white” and ‘Antique white”?

## Learn more from these resources:

- SBS Culture: The way you see colour depends on what language you speak
- MIT NEWS: Analyzing the language of color
- Wikipedia: Linguistic_relativity

## Colour idioms in English

What is an **idiom**? How do we use colour expressively in the English language?

> An **idiom** is a phrase that uses *figurative* language to express an idea or concept. The meaning of an idiom is more than the words mean: it’s an *extended* meaning.

> **Seeing Red**
>
> The idiom **“seeing red”** is a good example: we don’t actually mean that we see the colour red, but we understand it to mean **“being angry”** because that’s how the phrase has developed meaning over time through common use.

The phrase “seeing red” now has its own meaning in the English language. It might not have the same meaning in other languages (although some colour idioms can be similar across languages).

### English has lots of colour-related idioms. Some relate to emotions and moods, but others are more descriptive.

> **Green fingers**
>
> Saying someone has **“green fingers”** or **“a green thumb”**, means they are **good at gardening and growing plants**.

Read this article for some common examples of colour idioms in English.


1. Gladstone, W. 1858, Studies on Homer and the Homeric Age, gutenberg.org [www.gutenberg.org]
2. Bellos, Alex, 2010, "Through the Language Glass: How Words Colour Your World by Guy Deutscher", The Guardian, 12/06/2010, theguardian.com [www.theguardian.com]
3. (Gage, J. *Colour and Meaning*, Thames and Hudson, 2002, p.26
4. Darwin, Voyages of the Adventure and Beagle, 1839, darwin-online.org [darwin-online.org.uk]

## Interactive Content

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this Interactive Content online

Here are some useful links to library subject guide resources and other online resources to further your research.

- RMIT Library – Interior design subject guide

Books held at RMIT Library

- John Gage, *Color and Meaning: Art, Science, and Symbolism* University of California Press – 1st edition, 2000
- John Gage, *Color and Culture: Practice and Meaning from Antiquity to Abstraction* University of California Press – 1st edition, 1999
- *Color – Messages & Meanings: A PANTONE Color Resource,* Paperback – November 29, 2006, by Leatrice Eiseman (Author)
- *Pantone Guide to Communicating With Color,* Paperback – October 16, 2000 by Leatrice Eiseman (Author)

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# 1.4: Colour Aesthetics



Colour aesthetics can be simply described as how colour affects people. It's a mixture of the scientific, cultural and psychological aspects of colour theory.Figure 1.36. Bauhaus fabric samples by Otti Berger. Image attribution: Otti Berger artist QS:P170,Q2037742 Creator:Bauhaus, Book MET DP368775, on Wikimedia Commons,CC0 1.0.

Colour aesthetics explores how certain colours, or combinations of colours, are perceived by humans and how we react to them. What colours do we find attractive or ugly? Why do some colours look pleasing together and others clash? How does colour enhance our surroundings and living spaces?

It's useful to research and learn about colour aesthetics and selected artists and designers that played a significant role in this field over the last 100 years. This can help you to develop your own creative practice, and your personal approach to working with colour.

**This section covers the following topics:**

- Colour aesthetics in art and design:
  how colour aesthetics influenced the creative practices of some of the key figures in 20th century art and design and its relevance today
- Colour grading in photography and film: an introduction to colour grading and correction in photography and film – why it is used and cultural implications of standard colour-tests
- Contemporary colour trends and palettes used in design

# Colour aesthetics in art and design

## Early Modern Art



Figure 1.37. Wheat field with crows, Vincent van Gogh, 1890. Image attribution: Vincent van Gogh artist QS:P170,Q5582 Google Art Projectでのアーティストの詳細, Vincent van Gogh – Wheatfield with crows – Google Art Project, marked as public domain, on Wikimedia Commons

**Goethe**, **Chevreul** and **Ostwald** (See 1.1 History of colour theories for more details) did not have an ongoing influence on colour theory from a scientific perspective. However, they did have a lasting influence through the works of artists who were concerned with colour aesthetics, psychological colour and subjective colour from the time of the **Impressionist** movement, through to the **Abstract Expressionist** and **Colour Field** painters of the 20th century.

**Research and reflection activity:**

It's easy to find resources about early modern artists and their work with colour in art books and online publications.

Here is a small selection of artists from the **Impressionist**, **Expressionist**, **Fauvist**, **Orphic Cubist**, and **Futurist** movements who made significant contributions to the development of modern theories of colour in visual art.

Research three of the artists listed here – select artists' names to open a Google search in a new browser tab, and learn more about them and their work with colour:

- **Claude Monet**
- **George Seurat**
- **Vincent van Gogh** (Figure 1.37)
- **Paul Cezanne**
- **Henri Matisse** PDF file" data-quail-id="64">[1]
- **Andre Derrain**
- **Sonia Delaunay**
- **Robert Delaunay**
- **Giacomo Balla**
- **Umberto Boccioni**

Do you have a favourite artist from this time?

How does colour play a role in their work?

> Does understanding other artists' creative practices help you to develop your own practice?

## The Bauhaus influence

The German **Bauhaus** school (1919-1933) was an important site for experimentation and exploration of the aesthetics of colour and form, and how colour is subjectively perceived in different contexts. The work done by key designers and artists associated with the Bauhaus school is still influential.

Practitioners listed below all taught colour curricula at the Bauhaus school. They all had their own ideas and theories about colour aesthetics. Select artists' names to open a Google search in a new browser tab, and learn more about them and their work with colour:

- **Josef Albers**
- **Anni Albers**
- **Johannes Itten**
- **Wassily Kandinsky**
- **Paul Klee**

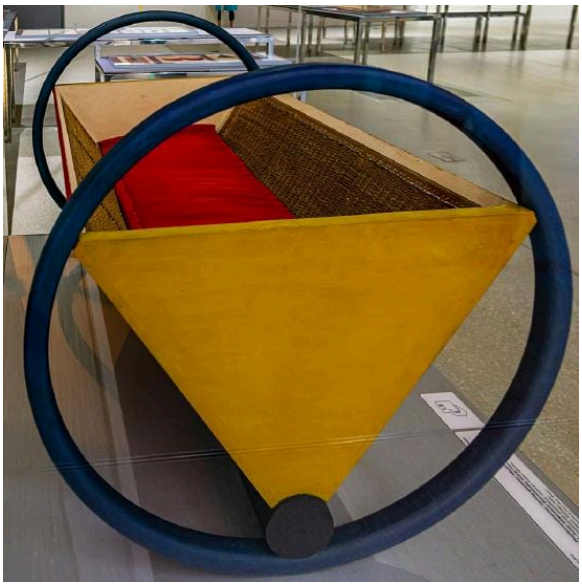


Figure 1.38.Bauhaus cradle by Peter Kelley. Image attribution: Peter Keler artist QS:P170,Q2076225 (Ausführung) Wassily Kandinsky creator QS:P170,Q61064, Bauhauswiege DSC9004, on Wikimedia Commons, CC0 1.0

The traditional primary colours: Red, Yellow and Blue, and the associated secondary and tertiary colours on the traditional colour wheel, formed the colour model used by Johannes Itten, Josef AlbersRMalexanderstreet.com [video.alexanderstreet.com] and others (Figure 1.38) as a basis for the Bauhaus colour curriculum, and for other schools influenced by the Bauhaus.

Albers and Itten both had a keen interest in colour relationships and how colours appear when placed side-by-side.

> Color is changing continually: with changing light, with changing shape and placement, and with quantity which denotes either amount (a real extension) or number (recurrence). And just as influential are changes in perception depending on changes of mood, and consequently of receptiveness.[3]

Publications by Albers nd Itten are still referred to in art schools today. You may find copies of these books in art and design school libraries:

Josef Albers, *Interaction of Colour*, *Homage to the Square*

Johannes Itten, *The Art of Colour*

## Mid-century Modern: into the colour field

In the mid-20th century, artists associated with **Abstract Expressionism**, **Colour Field** painting and **Post-painterly Abstraction** were working without figurative elements, using colour as the main feature of their paintings. Select artists' names to open a Google search in a new browser tab, and learn more about them and their work with colour:

- **Mark Rothko**
- **Barnett Newman**(Figure 1.39)
- **Kenneth Noland**
- **Clyfford Still**
- **Helen Frankenthaler**
- **Frank Stella**

These artists, and many others from the modern period, created significant artworks that have influenced creative practitioners of all kinds since that time. In the 21st Century, we continue to research and study these artists' works because of their impact. Students of art and design can learn much from exploring their use of colour.

Who's Afraid of Red, Yellow and Blue <span class=
IV" height="489px" data-cke-saved-src="/@api/deki/files/195016/2560px-
Barnett_Newman_at_Neue_Nationalgalerie_2369586886-1024x875_(1).jpg" src="/@api/deki/files/195016/2560px-
Barnett_Newman_at_Neue_Nationalgalerie_2369586886-1024x875_(1).jpg" style="width: 646px; height: 489px;" width="646px"
data-quail-id="265">

Figure 1.39. Who's Afraid of Red, Yellow and Blue IV (1969/70) by Barnett Newman. Image attribution: Rino Porrovecchio from Palermo, Italy, Barnett Newman at Neue Nationalgalerie (2369586886), on Wikimedia Commons, CC BY-SA 2.0

In Australia, there was a significant shift to abstract and colour field painting in the 1960s. The National Gallery of Victoria held an important and controversial exhibition titled "The Field" in 1968 which coincided with the launch of the new modernist gallery space in St Kilda Road (the current NGV International gallery).

This was a landmark exhibition which showcased the new work of young and emerging local Australian abstract artists. In 2018, this exhibition was re-staged at the NGV International space titled "The Field Revisited". Read about it here in this ABC News article, and visit the NGV website page to see examples of the abstract artworks and the artists that created them.

**Research and reflection activity:**

Research two of the artists working with abstraction listed in this section, and see if you can find two more artists from the NGV "The Field" exhibition.

- Do you have a favourite abstract artist?
- How does colour play a role in abstract painting?
- How does understanding these artists' creative practices help you to develop your own practice?

Note: the artists and designers listed on this page were not the only ones working with colour in new and experimental ways: this is an introduction to selected key figures in art and design. See linked resources and subject guides for more information on this topic.

### Further resources:

Ball, V. K. (1965). The Aesthetics of Color: A Review of Fifty Years of Experimentation. *The Journal of Aesthetics and Art Criticism*, *23*(4), 441–452. https://doi.org/10.2307/427666

David Briggs' website ***The Dimensions of Colour*** contains extensive academic and scientific information about colour theory. These two sections are particularly relevant to this page as they discuss modern colour theory:

- 11.2 Traditional and modern colour theory part 1: Modern colour theory
- 11.3 Traditional and modern colour theory part 2: traditional colour theory strikes back!

1. also see Matisse's publication *Notes d'un peintre,* 1908 (English version)(opens as a PDF file
2. RMIT students can access this video on Albers: RM, A. (Producer), & Moritz, R. (Director). (2012). Josef Albers - Homage to the Square: Against Deep Blue. [Video/DVD] ArtHaus Musik. Retrieved from https://video.alexanderstreet.com/watch/josef-albers-homage-to-the-square-against-deep-blue
3. quote by Josef Albers (Written ca. 1954 and published in numerous catalogues and articles and in various languages)

## Colour grading in photography and film




Figure 1.40. Image attribution: Metropolitan Print Company; Copyright 1896 by Raff & Gammon, Edison's Greatest Marvel-The Vitascope – Restoration, marked as public domain, more details on Wikimedia Commons

Since the beginnings of colour technologies in photography and film in the late 19th Century, attempts have been made to create realistic and accurate colour representation in photography and film.

**Colour grading** is the manipulation of colour to emphasise or **de-saturate** certain colours and adjust contrast, shadows and highlights. It is used to enhance the mood, emotion, or visual style of an image or film.

The practices of colour grading and colour correction began with traditional photography and film and continue to this day with digital media production.

> For an overview of colour technologies in non-digital photography and film, Barbara Flueckiger's website *Timeline of Historical Film Colors* is an extensive resource of over 250 individual film colour processes, from tinting and hand-colouring to contemporary colour film processes.

This page covers a selection of important developments in the production of colour photography and film

**Topics:**

- Technicolor
- The history of photographic test cards and racial bias
- Colour grading film for skin tones
- Colour grading techniques in digital photography and film

## Technicolor

You may have seen old movies that list Technicolor in their credits, such as *The Wizard of Oz* (1939, Victor Fleming, Metro-Goldwyn-Mayor) or *The Red Shoes* (1948, Michael Powell & Emeric Pressburger, The Archers).

Technicolor is a trademarked process for colour motion-picture that dates from 1932. The original process captured three black and white films at once using a very large and cumbersome camera with a light-splitting cube to capture red, green and blue light on each film. It then used a dye process to produce an opposite colour print – the red film becomes a cyan print, the green becomes a magenta print, and the blue becomes a yellow print. When the three colour films were laminated together, they reproduced something close to natural colour.

Watch this video for more details:

## How Technicolor changed movies (Phil Edwards, Vox)

Media attribution: How Technicolor changed movies, Phil Edwards, Vox on YouTube

You can learn more about Technicolor from the Eastman online research archive.

## The history of colour photographic test cards and racial bias

In the 1950s, cameras and colour film became cheaper and more available for anyone to use. The companies that made photographic film and the printers that produced photographs from the negatives required methods for testing whether the colour was accurate and realistic. At that time, the Kodak company had a monopoly on colour film and photographic printing in the western world.

The method of colour testing for photographic printing used images of people (usually women) on the test cards to ensure skin tone was accurate. This was problematic because Kodak originally only used models with white skin as testing controls. This means that there was **bias** in the way colour film presented people with darker skin tones.

These test cards were known as “Shirley cards”, because that was the name of the original model used in the Kodak skin tone standard cards.

It wasn’t until the mid-1990s that Kodak developed a multiracial Shirley card, but this was partly because companies that manufactured chocolate and wooden furniture had been complaining for years that photographic prints weren’t showing enough variations in the dark brown tones of their products.

Fuji film became the film of preference for photographing darker skin tones at that time, possibly because their colour processing favoured a different range of skin tones.

Watch this video to learn more:

## Colour film was built for white people. Here’s what it did to dark skin.

Media attribution: Color film was built for white people. Here’s what it did to dark skin, Vox on YouTube

It is fair to say that early colour film and printing techniques didn’t have the same range of colour dynamics as we have now, and

couldn't produce the best skin tones across all skin types. However, it is evident that the way chemical processes were developed at the time favoured showing light skin tones more accurately than dark skin tones.

Learn more about this topic from artists Hito Steyerl and Rosa Menkman: Behind White Shadows.

### Colour grading film for skin tones

More recently in cinematography, colourists have developed digital colour grading techniques to better represent all skin types without losing quality or stylised colour effect. Some significant examples of using colour grading in moving images to portray dark skin tones include the films Moonlight (2016, Barry Jenkins dir.) and Black Panther (2018, Ryan Coogler dir., Marvel Studios).

Watch the trailer here to see the different colour gradings used in this film:

### Moonlight | Official Trailer

YouTube Video

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

Media attribution: Moonlight | Official Trailer HD, A24, on YouTube

Moonlight director Barry Jenkins engaged colourist Alex Bickel, to create a colour grade for the film that increased contrast and colour saturation while preserving detail. The three chapters of the film were designed to look like different film stocks:

- Chapter 1 imitated the Fuji film stock to highlight the cast's skin tones.
- Chapter 2 imitated the Agfa film stock, which increased the cyan colour.
- Chapter 3 imitated a modified Kodak film stock.O'Falt, C. 2016, "'Moonlight' Glow: Creating the Bold Color and Contrast of Barry Jenkins' Emotional Landscape", IndiWire, 26/10/2016, accessed 10/11/2022">[1]

## Colour grading techniques in digital photography and film

You may have already used ***filters*** on your own digital media to adjust and enhance the colour of a photograph or video for social media or before you print it. Most image-capturing apps now have a range of colour filters that can immediately change the look of your image in many ways.

This is simple colour grading, and the same principle is applied to professional photography and film – although the processes can be much more technical and customised. Almost all films and TV series have colour grading applied to them. It can be surprising to see the original footage captured in the camera compared to how it looks **post-production**.



Figure 1.41. Colour grading example with increased saturation and contrast: before (left) and after (right). Image attribution: Image by Ioannis Ioannidis from Pixabay

Colour grading in film and video is an art, and colourists are skilled in manipulating colour using a range of digital techniques.

Colour *correction* is not the same as colour grading. Colour correction involves fixing problems with the original captured imagery, like editing out skin blemishes or matching colour between different scenes in a video, for example. Colour grading is more about the overall colour and visual style of the image or video.

You might have noticed that some movies you watch have a lot of deep blue and green tones, while others might have orange and cyan tones, very black shadows, or very vibrant reds. With colour grading, deliberate choices are made to adjust the hue, saturation, contrast, highlights and shadows of still or moving images to enhance drama or match visual themes.

All image and video editing applications currently used in the digital media industry have colour grading tools. Anyone working with digital photography and film can learn how to use these tools and apply colour grading to their digital media projects.

**Activities:**

1. Make a list of your three favourite films or TV drama series and analyse the colour grading in the video. It is likely that none of your choices are using film or video straight from the camera without any colour grading – unless you are watching a **Dogma 95**.
   - Are the colours similar or different in each of your selected videos?
   - Do certain types or genres (Action, Romance, Comedy, Sci-fi, Horror etc.) have the same colour style?
   - How does the colour add to your experience of what you are watching?
   - How can you improve your own images and videos with deliberate colour grading?
2. Explore the filters on your mobile device apps or the colour editing settings in your image or video editing software and experiment with adjusting the colour in your own photos and videos.

You can learn more about colour grading for video by doing these short **LinkedIn Learning** courses (free for RMIT students with login):

- Creating a short film – 11 – color grading
- Colour grading footage in-After-Effects
- Introduction to video color correction – understanding color theory

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1. >O'Falt, C. 2016, "'Moonlight' Glow: Creating the Bold Color and Contrast of Barry Jenkins' Emotional Landscape", IndiWire, 26/10/2016, <https://www.indiewire.com/2016/10/moonlight-cinematography-color-barry-jenkins-james-laxton-alex-bickel-1201740402/> accessed 10/11/2022

# Colour trends and palettes

A **trend** is a direction that is developing or changing – as with fashion, which is constantly evolving. **Colour trends** are how we describe certain colours or colour **palettes** (selected groups of colours that are used together) that become popular at different times. Knowing about colour trends is useful in design fields like fashion and textile design, interior design, product and packaging design and web design, where new products are continuously emerging.

Commercial colour charts are easy to find for paints and textiles. In design, the **Pantone Matching System (PMS)** for graphics and print and the **Pantone Fashion, Home and Interiors System (FHI)** for textiles and pigments have become industry standards for colour selection for a wide range of design and commercial production solutions.

The Pantone Colour Institute has also become known for its colour trend influencing. They select a “colour of the year” each year.

The 2023 Colour of the Year is:

PANTONE
18-1750
Viva Magenta



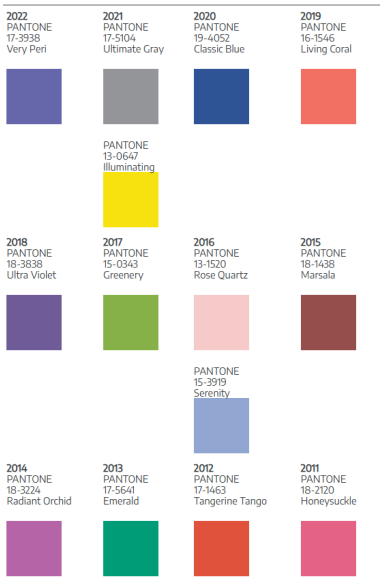



Table 1.3 Pantone Colour of the Year 2011-2022

Pantone past colours of the year.

## Aesthetics of colour palettes

A colour palette is a set of colours that a designer or artist chooses to work with on a project like an image, website, fashion range, product packaging etc.

Choosing the right set of colours can play an important role in how successful your design, artwork or product is and how users respond to it.

As previously discussed in this chapter, colour perception and aesthetic taste are subjective things, but colours do have common

links to our emotions and moods. Any artist or designer will have their preferred palettes for working with specific projects. However, if you have a design brief from a client, you may need to create a unique colour palette for your client's website or product. It can be difficult to know which colours work best together, and if those colours successfully symbolise or represent your client's business.

Many online tools can recommend currently trending and aesthetically pleasing colour palettes or can help you create your own palettes by using keyword searches. Other online tools allow you to upload images to create a colour palette from the colours used in the image, or use AI to create colour palettes based on machine learning.

**Activity:**

Here are some online tools that can help you to create your own unique colour palettes for creative projects. Try them!

**Colour palette generators**

- Canva color palette generator
- Adobe color wheel
- Colormind.io
- Coolors.co
- Colors.muz.li

See Chapter 3.5 Colour wheels and relationships for more information on colour palettes and an interactive colour wheel.

Also, see Chapter 3.4 Pigments and dyes for examples of famous artists' painting palettes.

# Test yourself: colour aesthetics

## A multiple choice quiz to test your understanding of colour aesthetics

(5 minutes or less)

### How did you go?

If you need to learn more about this topic, you can read this section again.

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# 2: PART 2- THE VISIBLE SPECTRUM

2.1: Introduction
2.2: The Physics of Light and Colour
2.3: Colour in Chemistry
2.4: The Eye- How We See Colour

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# 2.1: Introduction

As stated in Chapter 1, section 1.1, Sir Isaac Newton was the first to classify the visible spectrum as we know it today.

## This diagram shows the visible light spectrum and other types of non-visible electromagnetic radiation measured in nanometres (nm).

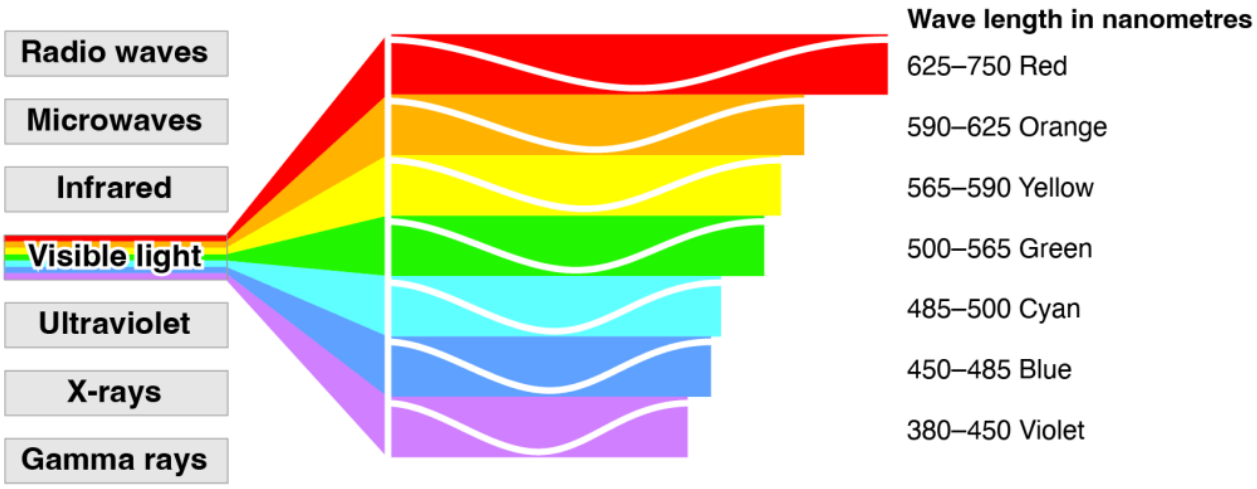



Figure 2.1. The light spectrum with visible wave lengths in nanometres, by RMIT, licensed under CC BY-NC 4.0.

The colours we see are based on wavelengths, and as Figure 2.1 shows, there are wavelengths that the human eye cannot see, like radio waves, X-rays, and microwaves. In the visible spectrum, violet rays, which are the shortest wavelengths are also the highest in energy. Red light wavelengths are the longest and the lowest in energy.

This chapter will focus on the visible spectrum, and the science-related aspects of colour vision. Each section will include information, links, resources, and learning activities to further develop your knowledge.

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# 2.2: The Physics of Light and Colour

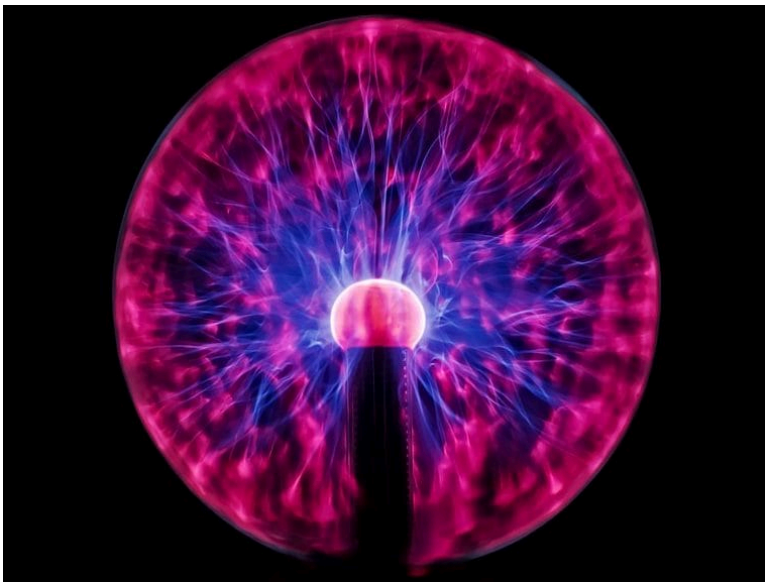


Figure 2.2 Plasma globe by Joshua_Willson via Pixabay, licensed under CC0.

**Physics** is the science that deals with energy and matter. To understand what colour is and how we see it, we need to explore the physical properties of light as a form of energy and how it interacts with matter – the objects we see.

This section explains the following physics-related topics in an introductory way with videos, links, and learning activities to help you to extend your knowledge of the physics of light and colour.

## Light: electromagnetic radiation

Light is a form of electromagnetic radiation. We often talk about light as **waves** because light is made from energy that is radiated in a wave pattern, but light also has properties that are like **particles**. Sometimes light behaves like waves and sometimes it behaves like particles. This may sound confusing – it is!

Watch this video to learn more about the weird physics of light waves and particles (approximately 10 minutes).

Media attribution: Is Light a Wave or a Particle? – Ask a Spaceman, Paul M. Sutter on YouTube

You can also read the article here.

For Colour Theory, we refer to light as waves to describe how light forms different wavelengths that we see as colours. Wavelength is the distance between each wave of light energy – and as shown in Figure 2.3, it is measured in **nanometres**. A nanometre is **one billionth of a metre**, 0.000000001 or $10^{-9}$ metres.

> **Electromagnetic spectrum**

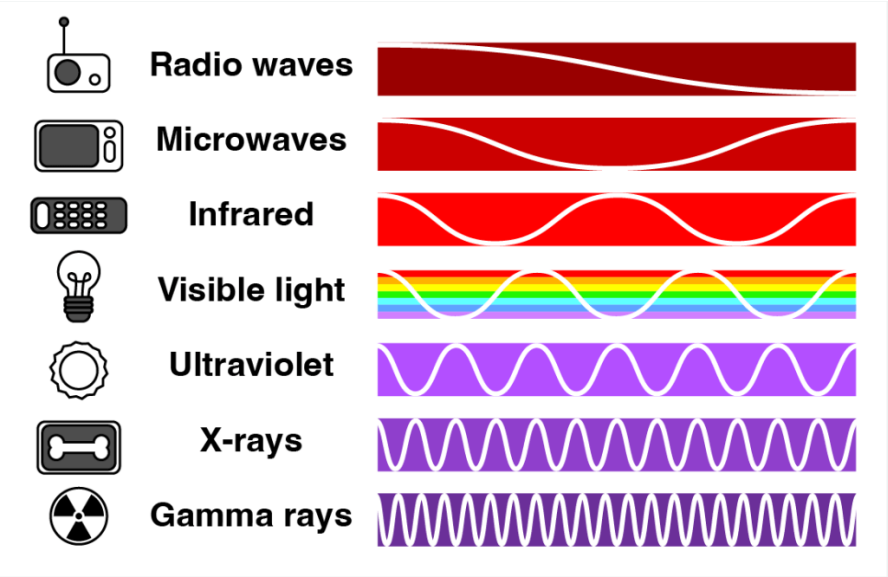



Figure 2.3. Electromagnetic spectrum diagram by RMIT, licensed under CC BY-NC 4.0.

The energy of a light wave is similar to that of a particle moving at the speed of light. However, even the smallest particles would not be able to travel at such high speeds in reality.

The term **photon** is used to represent the smallest quantity of light from any wavelength. It's also called a **light quantum** – an idea that began with **Albert Einstein**. The energy of a photon depends on the wavelength. Ultraviolet, X-rays and Gamma rays have the most energy and the shortest wavelengths. Radio waves, Microwaves and Infrared have the lowest energy and the longest wavelengths. The visible spectrum sits in between these wavelengths and is only a small part of the whole electromagnetic spectrum.

**Colour** is how we define specific wavelengths in the visible spectrum. For example, red light has wavelengths from approximately 630 to 700 nanometres. Blue light wavelengths are approximately 450 to 500 nanometres. It's difficult to say where one colour ends and another colour begins. Our definitions of colour by wavelength are based on our perception of colour with human eyes, and our classification of six main colours in the spectrum.

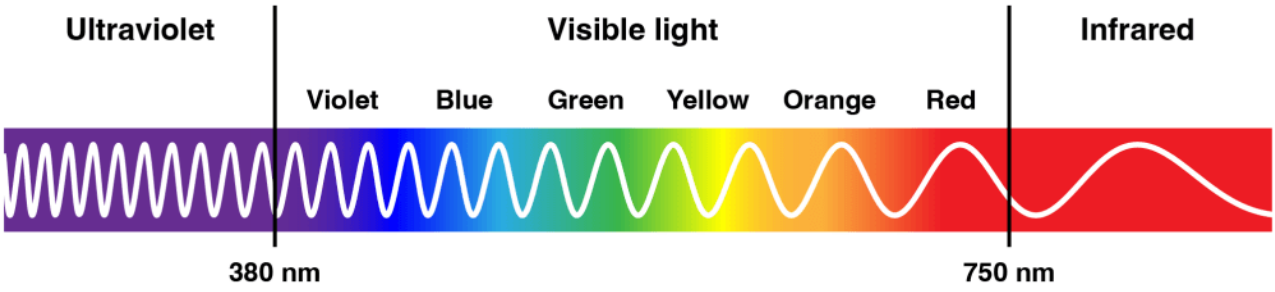



Figure 2.4. The visible light spectrum, by RMIT, licensed under CC BY-NC 4.0.

### Interesting Fact: Auroras



Figure 2.5. Aurora Borealis (Northern Lights), Alaska. Image attribution: United States Air Force photo by Senior Airman Joshua Strang, Polarlicht 2, marked as public domain, more details on Wikimedia Commons

Auroras like the Aurora Borealis (Northern Lights) and Aurora Australis (Southern Lights) are natural phenomena that occur near the North and South Poles of the Earth. Auroras are shimmering patterns of coloured lights that appear in the sky – usually in winter, when the sky is darkest at the poles.

Auroras are nothing like rainbows (which are caused by **refraction**), they are made from electromagnetic radiation (light) that is emitted when solar wind particles collide with charged particles in the earth's outer atmosphere – the *magnetosphere plasma*. Sun events like *coronal ejections* can cause more of these disturbances.

Auroras can occur on satellites, comets, and on other planets.

Learn more about the physics of light and colour and the history of theories of light.

# Optics 1: lenses and ocular devices

## What is Optics?

**Optics** is a branch of **Physics** – it's the science that deals with light. Optics explains how light energy behaves and interacts with matter. Some of the earliest recorded experiments in optics were done by ancient Egyptians, Mesopotamians, and Greeks using glass lenses and reflective materials like obsidian.

During the Middle Ages and Enlightenment periods, the significant work of scientists **Ibn al-Haythem (Book of Optics c1011)** and **Sir Isaac Newton (Opticks, 1704)** made contributions to the field of optics with their observations of the visible spectrum and how light moves through different substances, as mentioned in Chapter 1.1 History of colour theories.

Other significant developments, such as **Galileo's refracting telescope** (c.1609), also had a great impact on the fields of optics and astronomy. Since that time, many technological developments have expanded the field of optics to include both the visible and non-visible spectrum.

We use optics every day in so many aspects of our lives, including using our eyes to see. Optical glasses, mirrors, devices like cameras and digital devices, remote controls, microwave ovens, X-ray machines, microscopes that can show us cells and viruses up close, telescopes that explore the universe, optical fibre that gives us fast broadband internet, the solar panels we use to generate electricity – all these rely on technological innovations in optics.

Learning about optics is very useful for colour theory in science and creative fields such as art and design, because it has impacted many of the technologies we use in these fields. This page covers a selection of topics related to optics, many of which are used in creative and scientific practice:

**Part 1. Selected technologies and innovations that come from the field of optics**

- Lenses
- Camera Obscura and Camera Lucida
- Kaleidoscope
- 3D glasses

## Lenses

A **lens** is an optical device usually made from transparent polished glass or plastic that focuses or disperses light depending on its shape. Light passing through the material of the lens is bent – that is, it changes direction depending on the shape and thickness of the lens. The word lens comes from the Latin for ***lentil*** because the ***biconvex*** (curving outwards on both sides) shape of a lens looks a lot like a lentil. However, not all lenses are biconvex, some are ***biconcave*** (curving inwards on both sides) or combinations of convex and concave. Biconvex lenses focus light, whereas biconcave lenses disperse or spread light (see Figure 2.6).

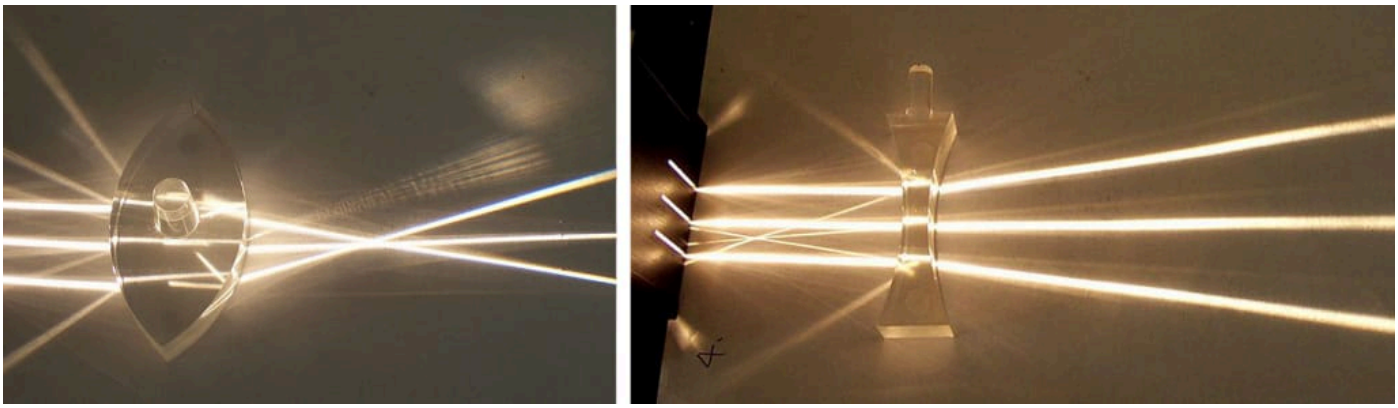


Figure 2.6. Examples of simple convex and concave lenses which can focus or disperse light. Image attribution: Large convex lens and Concave lens images released under the GNU Free Documentation License.

The most common lenses used in optical eyeglasses are ***meniscus*** lenses, which are *convex-concave* lenses that are customised to suit each individual's vision requirements.

Lenses are in many devices we use every day, such as eyeglasses, magnifying glasses, cameras, telescopes, microscopes, etc.

Learn more about lenses.

**Camera Obscura and Camera Lucida**




Figure 2.7. Camera Obscura engraved drawing. Image attribution: James Ayscough, 1755, marked as public domain, on Wikimedia Commons

A **Camera Obscura** (Latin for *dark chamber*) is a dark space used to create an image projection. It works with a room, tent or box which has a very small hole or lens on one side that projects an image from the outside of the space to the opposite wall on the inside of the space (Figure 2.7). The projected image is upside-down and back-to-front because light bouncing off objects outside the Camera Obscura enters the internal space through the hole or lens at an angle. Light from an object at the top-left of a scene outside the camera, will project onto the bottom-right of the inner wall of the camera.

The concept behind the Camera Obscura led to the development of the **photographic *camera*** – which is where the name comes from. Cameras we use today still work on the same principle as this device, which was created many hundreds of years ago.

Some historians speculate that prehistoric cave paintings may have been inspired by accidental Camera Obscura effects from small holes in tents or animal hides. The Camera Obscura was most notably used as an artist's device during the Renaissance and later periods of realism in painting to assist in the depiction of realistic scenes and accurate **perspective** in artworks. There are records of its use in ancient Chinese, Arabic and European cultures as a means of telling the time of day and year by the position of the sun inside the camera. It was also used to safely view phenomena like **solar eclipses**, which can cause eye damage if viewed directly.

Jump to **Activities** at the bottom of the page to learn how to create your own Camera Obscura **Pinhole Camera box** with a cardboard box, or turn your entire room into a Camera Obscura.

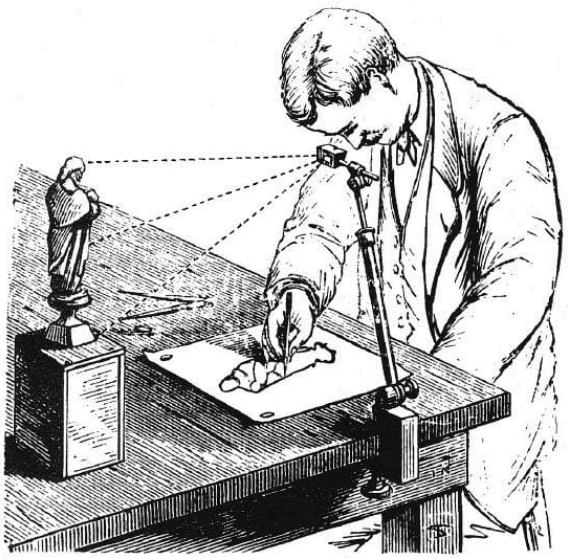


Figure 2.8. Camera Lucida diagram. Image attribution: Unknown author, Camera Lucida in use drawing small figurine, marked as public domain, on Wikimedia Commons

A **Camera Lucida** (Latin for *light chamber*) is a portable device that was developed after the Camera Obscura. The technology may have existed in the 17th century, but it wasn't patented until 1806. A Camera Lucida creates an optical illusion, where the scene in front of the artist is ***superimposed*** onto paper, which is usually on a flat surface like a table. The artist is able to look down into the device, which uses glass, a one-way mirror, or a prism, and see both the image of the scene in front of them, and the drawing on the paper combined together. See Figure 2.8 which shows a diagram of how a Camera Lucida is used.

The artist can then trace the superimposed image (which is an illusion created by the device) and create an accurate representation of the scene with correct proportions and perspective on the paper below. It was much easier to use than the Camera Obscura because it didn't require a darkened space, and you could use it anywhere in any light conditions. The technology of the Camera Lucida is similar to that used in microscopes that use mirrors to reflect the contents being viewed up into a lens that magnifies the image.

Artists used both of these technologies to assist in the depiction of realistic scenes in paintings and other art forms. Camera Lucida devices were also used by biologists and naturalists to create scientific illustrations.

Artist David Hockney wrote a controversial book where he claimed that many famous Old Master artworks were, in fact, created with optical devices like these. Some art historians were upset by this claim – they thought that Hockney was accusing the Old Masters of 'cheating' because of the suggestion that the artists hadn't recreated the scenes in the paintings by eye alone. This implied that these Old Masters were less technically skilled than previously thought.

Along with physicist Charles M. Falco, Hockney claimed that many of the developments in realistic painting from the time of the early Renaissance (c.1430) were due to the technological development of optics devices. This is known as the **Hockney-Falco Thesis.** They didn't consider using optical devices as 'cheating', rather they considered it part of the set of tools and devices artists could use in their work. Artists still require skill in painting techniques and visual style to create great masterpieces.

Hockney, David (2006). *Secret Knowledge: Rediscovering the Lost Techniques of the Old Masters*. Thames and Hudson. ISBN 9780500286388.

This video explores some of Hockney and Falco's claims:

Media attribution: A History of how Optics Has Helped Artists Create Better Paintings, Inside Science, on YouTube

**Kaleidoscope**

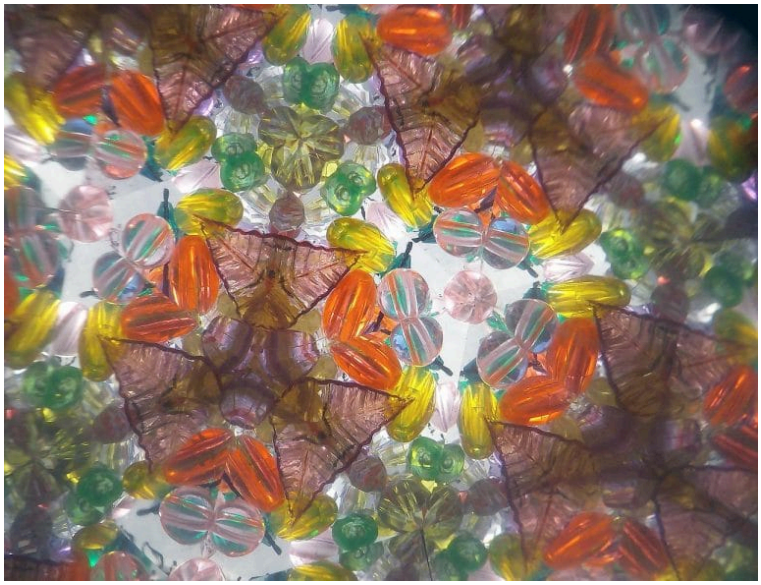


Figure 2.9. Example of the view looking through a kaleidoscope with coloured glass beads. Image attribution: Albarubescens, Rotational symmetries in designs produced by a kaleidoscopeDSCN2440, on Wikimedia Commons, CC BY-SA 4.0

**How does it work?**

Kaleidoscopes were first invented as toys in 1816 by Scottish physicist Sir David Brewster, but they can also be useful devices for designers and artists because they create complex and colourful symmetrical patterns. A kaleidoscope is usually made from a tube with angled mirrors inside of it that reflect light waves. Light usually travels in straight lines, but if it hits a shiny surface like a mirror, the light waves bounce back at a similar angle – like a bouncing ball.

Some kaleidoscopes have bits of coloured glass, beads or shiny objects inside them, so when you look into the tube, you see interesting geometric patterns made from these colourful objects and the reflected light from the mirrors (Figure 2.9). Other kaleidoscopes have lenses in them that bring light from outside objects into the kaleidoscope, and the patterns are made from the image you are viewing through the kaleidoscope tube.

If you rotate the kaleidoscope while looking through it, you can change the coloured pattern by shifting the coloured objects around or changing the light that the mirrors are reflecting.

You can now install mobile device apps that simulate a kaleidoscope effect using your camera or coloured geometric patterns, and you can save these images to use in creative projects. You can also get kaleidoscopic lenses that can be placed over a camera lens which add interesting patterns to a photographic image.

Learn more about kaleidoscopes from this text: *The kaleidoscope, its history, theory and construction with its application to the fine and useful arts* by Sir David Brewster, 1858 on the Internet Archive.

View Activities below to make your own Kaleidoscope.

## 3D glasses

**Why do we have two eyes?**

We have evolved to have two eyes (**binocular vision**), perhaps partly because there is less risk of total blindness if one eye is damaged. But have you ever thought about how we have two eyes but only see one image? The way our eyes work with our brains allows us to see in 3 dimensions (3D), and this is very useful for judging distances between objects and spatial navigation in the world.

More on human vision in 2.3 The human eye – how we see colour.

### Stereoscopic photography

Binocular vision has also led to technological developments that try to replicate our 3D vision using different devices. The earliest experiments with this were with stereoscopic photography, where two photographic images were captured at a small distance from each other (similar to the distance between human eyes). These two photographs were placed in a viewer so that each eye views a different image (Figure 2.10). The brain interprets this information as a single image, and it appears that we are looking at a 3-dimensional scene.

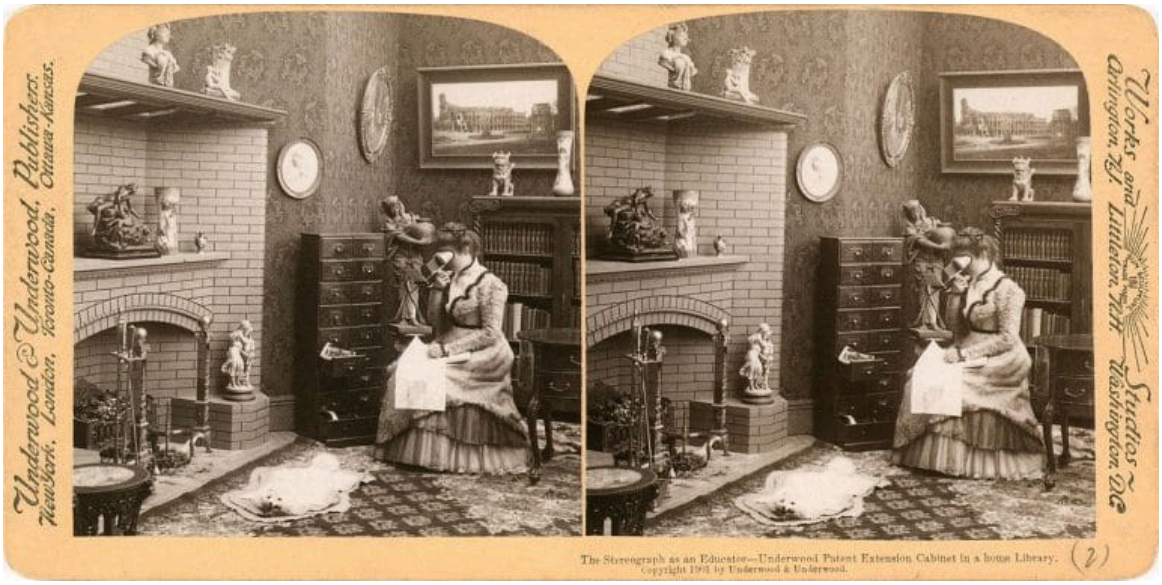



Figure 2.10. Example of a stereograph image depicting someone viewing a stereograph image through a stereoscope. Image attribution: Underwood & Underwood, Stereograph as an educator, marked as public domain, on Wikimedia Commons. Select image to enlarge.

### Anaglyph 3D – red/blue 3D glasses

A similar principle is used with the Anaglyph 3D technique, which overlays two images of different colours that are slightly apart. Usually, one image is red, and the other is cyan (Figure 2.11). To view this kind of image in 3 dimensions, you need special glasses with different coloured transparent filters for each eye.

The eye looking through the red filter only sees the cyan image (as a black image), and the eye looking through the cyan filter only sees the red image (as a black image). This is because these two colours are opposites and their light waves do not pass through the filter of the opposite colour.

The effect is the same as the stereoscope because the brain interprets these two images as one, which appears as a 3-dimensional scene.

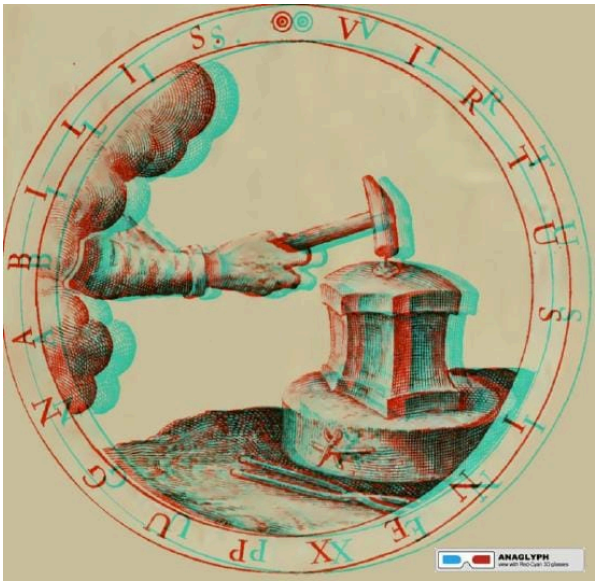



Figure 2.11. Anaglyph image for red-cyan 3D glasses. Image attribution: John Johnston from Glagow, Scotland, Hammer anaglyph (14656149338), on Wikimedia Commons CC BY-SA 2.0

**RealD 3D**

**RealD 3D** cinema technology is a **polarised** 3D system that uses **circularly polarised light** to create stereoscopic image projection. The principle for the polarising glasses we wear now for viewing 3D cinema is the same principle as the original stereoscope – the film we are viewing is actually two sets of moving images projected with a special projector that alternates right-eye frames and left-eye frames, switching between them 144 times per second

These separate projections for each eye are made with a special polarising screen that switches the polarisation, so each eye only sees the frames that match the polarisation of the glasses. This is what gives us a realistic 3D effect (Figure 2.12).




Figure 2.12. Two pairs of RealD 3D cinema glasses demonstrating polarising effect. Image attribution: Fritz Jörn at English Wikipedia, TwoRealDglassesblackening, marked as public domain, on Wikimedia Common

**Activities**

**Pinhole camera – make your own Camera Obscura box**

You can make one with any cardboard box:

YouTube Video

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

Media attribution: How to make a Pinhole Camera, George Eastman Museum on YouTube

or watch this video to learn how to turn your room into a **Camera Obscura:**

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

Media attribution: How to Turn a Room into a Camera Obscura, George Eastman Museum, on YouTube

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

Media attribution: How It's Made: Kaleidoscopes, Science Channel, on YouTube

Learn more here about the history of optics.

# Test yourself: electromagnetic spectrum, lenses and ocular devices

## A multiple choice quiz to test your understanding of the electromagnetic spectrum, lenses and ocular devices

(5 minutes or less)

# Optics 2: electronic technologies and spectral analysis

Learning about optics is very useful for colour theory in science and creative fields such as art and design, because it has impacted many of the technologies we use in those fields. This page covers a selection of topics related to optics, many of which

are used in creative and scientific practice.

**Part 2. Selected technologies and innovations that come from the field of optics**

- Laser
- Optical fibre
- Photovoltaic cells
- Spectral analysis in astronomy

# Laser

## How is it different to normal light?

Albert Einstein's paper *On the Quantum Theory of Radiation* (1917) theorised the physics of **lasers** long before they were first created and used in 1960 by American engineer Theodore Harold Maiman. The word **LASER** is, in fact, an acronym: **Light Amplification by Stimulated Emission of Radiation.** A laser light is different from a common light devices because it is a ***coherent*** light source – which means that a laser can be a very narrow spectrum of light – only one colour (temporal coherence) that can be focused on a very small spot (spatial coherence). This is unlike other lights, which have a broader spectrum and radiate out in multiple directions. Lasers can be very powerful because of this coherence. An example of this is laser cutting technology, which uses a very powerful beam of light to heat very small areas of materials like metal or wood to melting or burning point – which "cuts" the material very precisely.



Figure 2.13. Example of six different types of laser. Image attribution: 彭家杰, LASER, on Wikimedia Commons CC BY-SA 3.0

## How does it work?

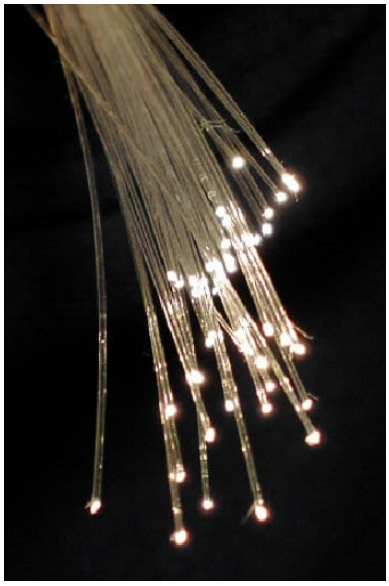
A laser is made with a tube that is filled with some type of gas, liquid or crystal material. The tube has mirrors at both ends, but one of the mirrors is partially transparent to allow some of the light to pass through it.

Energy is applied to the material in the tube – this could be a powerful light source, or some other source of energy like gamma rays. This energy also causes the material in the tube to produce light (photons) by exciting the atoms inside it. The photons bounce back and forth between the mirrors at the ends of the tube, which creates more photons. Some of these photons escape the tube through the mirror that is partly transparent, and this is what makes a laser beam (Figure 2.13). Light from a laser travels in a straight line and doesn't get weaker the further it gets from its source, unlike radiant light. This makes it very useful across long distances.

Lasers re used in lots of ways – in industrial and commercial processes such as in cutting tools, barcode scanners, and laser printers – or at home in optical disc players like DVD and Blu-ray, laser pointing tools, etc.

Learn more about lasers here

## Optical fibre



Optical fibre is made from very thin, transparent fibres of glass (silica) or plastic that are a tenth of the thickness of a human hair. These fibres are able to transmit light from one end to another very efficiently by bouncing photons along the length of the fibre.The photons don't escape from the fibre because of a phenomenon called total internal reflection – the photons bounce off the walls at an angle and keep bouncing along until they reach the end of the fibre. Optical fibres are also covered in a different layer of glass cladding that helps keep the light inside the optical fibre tube until it reaches the end (Figure 2.14).Figure 2.14. Optical fibres. Image attribution: BigRiz, Fibreoptic, on Wikimedia Commons, CC BY-SA 3.0

This technology can be used as a form of lighting, and is very useful in lighting small spaces that are difficult to access, such as in medical procedures. You can view internal organs with optical fibre cables without having to cut a body open (**Endoscopy**). This method of light transmission is also used for telephone calls and to send data across the Internet (**Broadband**) through specially developed fibre optic cables that can transmit very large quantities of information very quickly by encoding data in pulses of light.

Optical fibre is a better material than traditional copper wire for transmitting data for a number of reasons:

- there is less signal loss than wire – which means fewer amplifiers are needed to carry data long distances
- there is no electromagnetic interference from other cables – which can happen with copper wire
- it has a higher bandwidth – fibre optic cables can carry a lot more data than equivalent copper wires.

Learn more about optical fibre.

# Photovoltaic cells – solar electricity generation

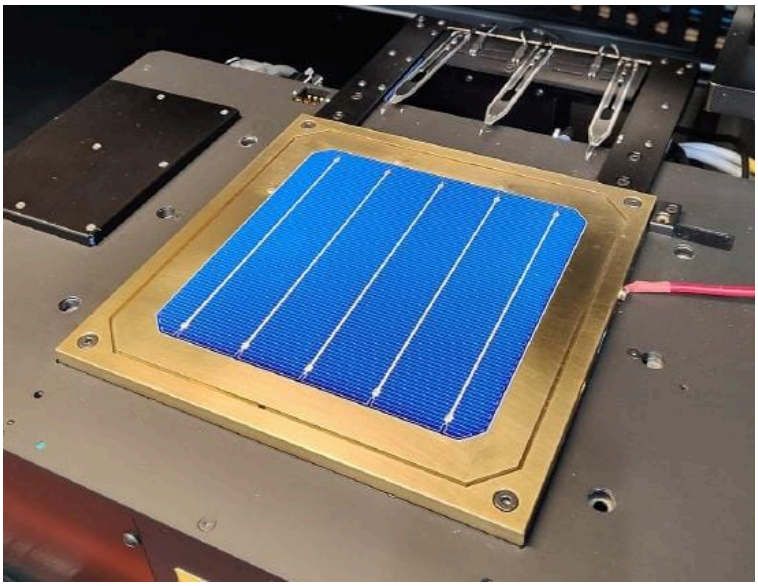


Figure 2.15. A silicon photovoltaic cell. Image attribution: Radiotrefoil, Silicon heterojunction solar cell, on Wikimedia Commons CC BY-SA 4.0

A **photovoltaic cell (PV cell)** (or solar cell) is a special type of semiconductor that converts visible light into **direct current (DC)** electricity. Some PV cells can also convert infrared or ultraviolet radiation into DC electricity. Solar electric systems like the panels we put on our roofs for electricity and hot water, or the little grey squares that power small devices like garden lights, use PV cells to generate power that can be used immediately or stored in a battery for later use (Figure 2.15).

In simple terms, a PV cell is made from two layers of crystalline silicon – one layer is positively charged, and the other is negatively charged. When photons enter the layers of the cell, this generates a flow of electrons from the atoms in the cell material, creating an electrical charge of DC electricity. For solar panels in our homes, the DC electricity is changed into **alternating current (AC)** electricity by an ***inverter*** device.

Learn more about photovoltaic cells and how they work.

## Spectral analysis in astronomy



Figure 2.16. Anglo-Autralian telescope at Siding Springs Observatory. Image attribution: Ahilan Parameswaran, Anglo-Australian telescope at Siding Springs Observatory, on Wikimedia Commons CC BY-SA 3.0

A **spectrometer** is a very useful device in astronomy. It splits lightwaves into different parts of the spectrum, which can then be measured and analysed to find out what planets, stars, galaxies and other celestial bodies are made of – even at great distances. It can also detect the speed and direction of their movement. This is called **spectral analysis**.

In 1868 a **spectroscope** was used to detect **helium** for the first time by using a prism to spread out light from the sun. An unusual yellow line was observed in this prism which was determined to be helium.

Learn more about spectral analysis from this CSIRO resource.

Learn more here about the history of optics

# Why are things different colours?

**Why do different objects we see around us appear to be different colours?**

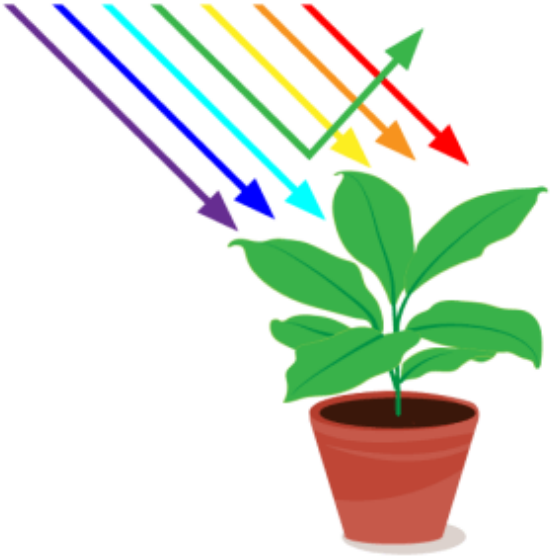
Objects themselves do not create colour (unless they have luminescence – see this section in the Chemistry chapter for more details). What they do is reflect and absorb the spectrum of light waves in different amounts – which includes light waves outside of the human visible spectrum.



For example: a tomato appears to be red because it's absorbing most of the blue, green and other colour light waves (taking those photons into its atoms) and reflecting red light waves out (Figure 2.17). This is what we detect with our eyes and process with our brains. If it's night-time and there is no light shining on the tomato, it doesn't appear red because there are no light waves reflecting off it. The tomato is not generating its own colour. The red colour we see in a tomato comes from a chemical called Lycopene which is a bright red pigment found in other red fruits too. Lycopene absorbs certain light waves and reflects red – this is what we see when we look at a tomato in the light.Figure 2.17. Tomato with light waves reflecting red light, by RMIT, licensed under CC BY-NC 4.0 using tomato by Mostafa Elturkey via Pixabay, CC0.

It's the structure of **molecules** that objects are made of that determines which light waves are absorbed and which are reflected. The electrons within those molecules have energy states that determine which types of energy they can absorb and reflect.

See Additive and subtractive colour systems in this resource for more information.



The reason that most plants and tree leaves are green is because of a pigment called chlorophyll which is used for photosynthesis. Photosynthesis requires red and blue light waves that the plant transforms into chemical energy. The plant doesn't need the green light waves so this is reflected out and that's what our eyes detect (Figure 2.18).Figure 2.18. Plant with light waves reflecting green light by RMIT, licensed under CC BY-NC 4.0 from plant pot by Satheesh Sankaran via Pixabay, CC0.

Some plants have flowers that reflect lightwaves humans can't see – like ultraviolet (Figure 2.19). However, certain insects and birds can see these light waves as colours and are attracted to the flowers as a source of food, which also pollinates the plants, or spreads their seeds so they can propagate. The plants have evolved to use this light-reflecting ability to assist their development, just like the insects and birds have evolved the ability to see ultraviolet light waves to assist their growth too.

This website ***Flowers in Ultraviolet* by Bjørn Rørslett**, has a very detailed list of flower images showing how they look to humans and how they would look if we could see ultraviolet light waves.



Figure 2.19. Mimulus flower photographed in visible light (left) and ultraviolet light (right) showing a dark nectar guide visible to bees but not to humans. Image attribution: Plantsurfer, Mimulus nectar guide UV VIS, on Wikimedia Commons, CC BY-SA 3.0

See How animals see colour in this resource for more information.

**Gemstones**



Figure 2.20
. Gemstones in a range of col
ours. Image attribution: Arpingstone, Gem.pebbles.800pix, marked as public domain, more details on Wikimedia Commons

Just like all other objects, gemstones absorb and reflect light waves and we perceive the reflected waves as different colours (Figure 2.20). Rubies are red and emeralds are green because of the atomic structures of their elements, including impurities that are also mixed in.

To some extent, the colours of gemstones seem to correspond with where they lie on the periodic table of elements. This corresponds with the behaviour of electrons in their atoms. For example, diamonds are made of carbon – which is on the first level of the periodic table – and these elements are usually colourless. Coloured diamonds are due to impurities and imperfections in the stone such as traces of nitrogen, sulphur or boron.

Learn more about gemstone colour from the Gem Society's Gemology page.

## Test yourself: electronic technologies, spectral analysis and different colours

### A multiple choice quiz to test your understanding of electronic technologies, spectral analysis and different colours

(5 minutes or less)

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# 2.3: Colour in Chemistry

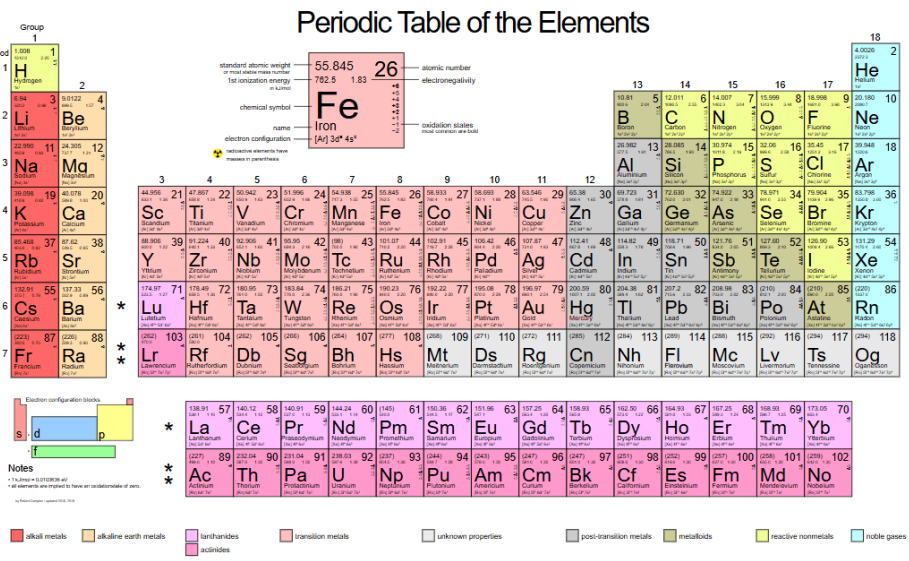



Figure 2.21. Periodic table of elements. Image attribution: 2012rc, Periodic table large, on Wikimedia Commons, CC BY 3.0

The science of chemistry deals with chemical elements – which are the substances of matter (Figure 2.21). Chemistry also deals with the properties and behaviours of these substances when mixed and the development of methods to create new substances.

The relationship between chemistry and colour is complex. Chemical processes are used to create colours that we use every day, and colour is used in chemistry to measure and analyse substances and chemical processes. It's useful to learn about this aspect of colour theory if you're working with colour materials in creative and scientific fields.

This section covers selected topics that explain the relationship between colour and chemistry (you can also find additional information in section

3.5 Colour systems: paint pigments and dyes)

# Spectrophotometry and colorimetry

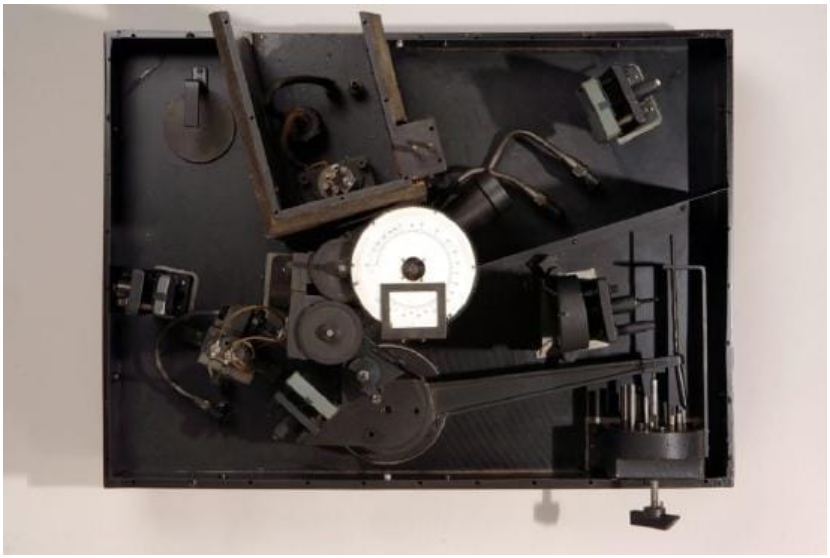


Figure 2.22. Beckman Ir-1 Spectrophotometer, c. 1941. Image attribution: Chemical Heritage Foundation, Beckman Ir-1 Spectrophotometer, ca. 1941, on Wikimedia Commons, CC BY-SA 3.0

**Spectrophotometers** and **Colorimeters** are both used to accurately measure colour, which is important in some scientific processes and also for matching colours for commercial production of products where colour accuracy is essential. They are both complex devices that are used in many areas of chemistry – and biochemistry in particular. Both use light and a solution (liquid) to measure the absorption of light

A **Spectrophotometer** (Figure 2.22) measures the reflection and intensity of light for all colours – including those colours that aren't part of the visible spectrum. It measures the exact wavelengths of light – not just the primary colours, by passing a beam of light through a ***diffraction grating*** which splits the light into different wavelengths. A spectrophotometer is used to detect the purity of substances, to detect DNA and RNA concentrations in a sample, and lots of other biomedical analytics

A **Colorimeter** (Figure 2.23) measures how much of a particular colour from the visible spectrum is in a solution by shining light through coloured filters or shining LED lights through the liquid. The device then measures how much of each colour is absorbed. It measures the three additive primaries (RGB) of coloured light. It can be used for blood analysis, detecting soil and food nutrients, chemical reaction levels, monitoring bacteria growth in biological experiments, etc.

Learn more about both devices




Figure 2.23. Colorimeter. Image attribution: Sonal Shinde, Colorimeter, on Wikimedia Commons, CC BY-SA 4.0

## Metamerism– colour perception and matching



Figure 2.24 Room interior with two light sources. Image by 5460160 via Pixabay, licensed under CC0.

> If you work in fashion, interior design or any industry where colour matching is very important, it is useful to understand the concept of colour *metamerism* and how it can affect the colours you use, how you display objects, products, and creative works, and how you use lighting in different environments.

Have you ever decided to wear all black clothes that look the same colour in your bedroom, but when you go outside, you notice they are all slightly different? Some black garments are more reddish-black, others slightly more green or blueish-black?

Have you ever chosen a carpet or paint for your home that you thought would match your furniture, but once you have it in your home, it looks completely different? It might also appear to be different colours between day and night, or on sunny or overcast, cloudy days.

These are examples of **Metamerism,** or in fact, ***illuminant metameric failure***. The light in your home can be different colours from room to room and also a different colour to the sunlight outside. Some colours look the same under certain light sources but different under other light sources, which can include incandescent, fluorescent, LED or sunlight.

We could also say that colour blindness is a form of metamerism – ***observer metameric failure*** – because people see colour differently depending on their biology and the functionality of their eyes – as outlined in the sections on colour blindness and vision difference in this resource

This also relates to the difference in colour on digital screens. You might design a website with a very specific colour palette, but you can't guarantee that everyone who views your website will have a screen that is properly calibrated to accurately show the colours you selected. You can test whether your computer or mobile device is "colour blind" by following some of the steps on this website: Is Your Computer Color Blind?.

## How does Metamerism work?

Metamerism is the term we use when colours match under one lighting condition but not another. Colours that do match in this way are called **metamers**. It's based on the science of how different coloured substances absorb and reflect light, the amount of electromagnetic radiation, and which wavelengths of the visible spectrum are reflected or emitted.

> **A practical example of a colour metamer is using two different methods of creating orange paints that appear to be identical**
>
> You can create an orange paint by:
>
> 1. mixing red and yellow paint pigments to create what the eye perceives as orange
> 2. using a ready-made orange paint pigment that was made with different chemicals to the red and yellow pigments.
>
> Your eyes will see the same colour even though the two oranges were created with completely different pigments that reflect slightly different light wavelengths.

When colours that should be the same don't match under different lighting conditions and are perceived differently, this is metameric failure. Some colours are more prone to metameric failure such as whites, greys, beiges, blacks, pinks and mauves. This is where the science of **colorimetry** becomes important for testing colour consistency and the specific wavelengths of light reflected or emitted.

## How to prevent metameric failures (colour mismatches)

If you are choosing fabrics for a fashion collection and you want them to match, you should collect swatches and samples of fabrics and accessories that will go together in an outfit or ensemble and lay them out under different lights to make sure they match and look good together.

For example, you might think you have the perfect matching zip, buttons, sewing thread and bias binding for a cotton dress, but these items are made from different materials (nylon, plastic and metal) to the cotton dress fabric. They might look the same in one type of light, but if you look at them under a different light source, they might reflect different amounts of light wavelengths and appear different to your eyes.

This is because the dyes and pigments colouring these materials may have slight chemical differences and therefore reflect light differently.



Figure 2.25 T-shirts in rainbow colours. Image attribution: Photo by Greg Rosenke on Unsplash

For the same reason, if you are decorating a house, it's a good idea to try sample paint pots or get carpet and fabric samples and put them on the floor or walls to make sure you have the right colour for the environment and where the light falls. You also need to check if the colours match under daylight from the windows and under the artificial lights in your home.

With digital media, it's impossible to know if your viewers have screens that are calibrated. It can help to test your website on as many different types of screens and, if possible, older technology, where screens might not work that well or may not have good brightness and contrast. This way, you will know if your colour designs will look good under different conditions that are out of your control. You could also encourage your audience to take the computer colour blindness test mentioned above.

# Test yourself: is it illuminant or observer metameric failure?

## A multiple choice quiz to test your understanding of metameric failure

### (5 minutes or less)

If you need to learn more about this topic, you can read this section again: 2.2 Colour in chemistry

# Luminescence

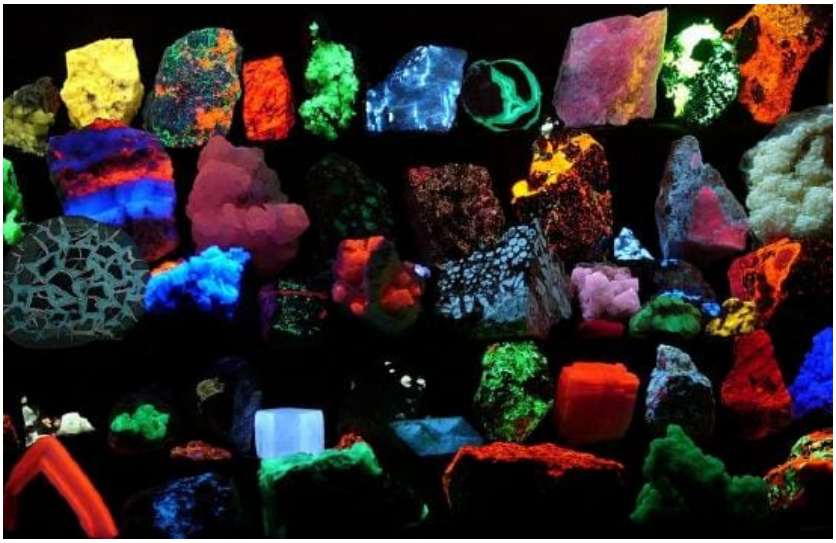


Figure 2.26 Fluorescent minerals. Image attribution: Fluorescent minerals (Hgrobe 06:16, 26 April 2006 (UTC)) – credit: Hannes Grobe/AWI, Fluorescent minerals hg, CC BY-SA 2.5, on Wikimedia Commons

**Luminescence** is the term we use to describe when substances spontaneously emit light. It's also described as "cold radiation" because it can happen to substances that aren't heated.

There are many different kinds of luminescence, and you may already know some of them because they are quite common. Here are a few examples of luminescence and how they work:

## Photoluminescence– resulting from absorption of photons

**Fluorescence**: photons immediately radiate visible light when ultraviolet light waves hit a fluorescent substance. Examples include fluorescent paint pigments, textiles, fluorescent lights, and blacklight inks and dyes that glow when you shine an ultraviolet light on them (Figure 2.27).

**Phosphorescence**: when a phosphorescent substance is exposed to short wavelengths of light (high energy), it glows by absorbing the light and emitting it at a longer wavelength (low energy). Photons may radiate for a prolonged period of time after the light source is removed. Glow-in-the-dark toys and paints are good examples of this.



Figure 2.27. Fluorescent clothes that glow with UV blacklight. Image attribution: Black light theatre Prague, Black light theatre Prague HILT 13, CC BY-SA 4.0, on Wikimedia Commons

What is the difference between fluorescence and phosphorescence? Phosphorescent substances continue to emit photons for a longer period of time after the light source is removed, whereas fluorescent substances tend to emit photons for a shorter time.UV blacklight"

## Chemiluminescence – from chemical reactions

Glow sticks are a good example of **chemiluminescence**. When you crack a glow stick, two chemicals are mixed together that produce a reaction. This reaction excites electrons in the atoms and they emit photons. This reaction is only temporary and you can't "recharge" a glow stick. You can only create this chemical reaction once.

**Bioluminescence** is a form of chemiluminescence. Marine creatures, fireflies, algae (Figure 2.28), bacteria and other types of organisms that glow in the dark create light through chemical reactions that occur in their bodies. It happens when a light-emitting molecule reacts with a certain type of enzyme that the animal produces.

Learn more about bioluminescence.

Watch a short video of a surfer on a bioluminescent wave here.

## Electroluminescence – from passing an electric current through a substance

LEDs (Light Emitting Diodes) are semiconductor devices that emit light when an electric current is passed through them. The colour of LED lights depends on the amount of energy passed through the semiconductors, which then determines the energy of the photons. Different amounts of energy produce different light wavelengths and therefore different colours (Figure 2.29). White light LEDs are created by using multiple semiconductors or a layer of light-emitting phosphors on the semiconductor device. It's a combination of fluorescence and electroluminescence. While it is possible to create white light from red, green and blue LEDs, this isn't the best method for colour rendering as only a narrow band of light wavelengths is used. The first LEDs emitted low-intensity infrared light. Visible and ultraviolet light LEDs were developed later.



Figure 2.29. Red green and blue LEDs. Image attribution: R, G, and B LEDs [7]. by PiccoloNamek, Uploaded to English Wikipedia under GDFL-self (GNU Free Documentation Licence) by the author, on Wikimedia Commons

## Radioluminescence – light produced by bombardment with ionising radiation

**Radioluminescence** happens when light is generated from a substance that is bombarded with ionising radiation, such as alpha particles, beta particles, or gamma rays. Dials on watches and clocks that glow in the dark are made from luminous paint containing the radioactive substance **Radium** (Figure 2.30).

Radium paint is a toxic substance and it created serious health problems for those who worked with it to create watch, clock and instrumentation dials. See Problematic colours in this resource for more information about the *Radium Girls* who worked in the factories that produced these radium dials.

Radium-based paints were replaced with **Promethium** and **Tritium** later in the 20th century as they have much lower radiation, making them safer to use.




Figure 2.30. Radium clock dial from the 1950s. Image attribution: Arma95, Radium Dial, CC BY-SA 3.0, on Wikimedia Commons

## Mechanoluminescence – physical pressure applied to substances like crystals

**Piezoelectricity**: the devices that light gas stoves, grillers and some lighters use ***piezo ignition*** (Figure 2.31). This mechanoluminescence works when pressure is applied to a PZT crystal (lead zirconate titanate) with a small hammer, which produces a sudden high voltage and generates an electric spark that ignites the gas.



Figure 2.31. A Piezo ignition device. Image attribution: Petteri Aimonen, Piezo igniter, marked as public domain, on Wikimedia Commons

There are many other kinds of luminescence not included in this resource. Learn more from this Wikipedia page.

# Test yourself: what type of luminescence is this?

### A multiple choice quiz to test your understanding of types of luminescence

### (5 minutes or less)

### How did you go?

If you need to learn more about this topic, you can read this section again: 2.2 Colour in chemistry

# Colour chemistry 1: animals that can change colour



Figure 2.32 Blue ringed octopus. Image by Rickard Zerpe on Wikimedia Commons, licensed under CC BY-SA 2.0.

There are many ways that colour is involved in chemical processes. Some of these processes occur naturally – as with certain animals that can change their colour by **cell signalling** (Figure 2.32). Some processes are used for medical diagnostic tests that help to keep us healthy – like COVID tests. Other processes are used to measure chemical substances and reactions in laboratories, for creative purposes like photography and making art materials, or simply for entertainment like fireworks.

The four pages in this section explain some examples of colour processes in chemistry with links to further information, and practical learning activities that are simple science experiments you can do at home.

## Animals that can change their colour

Only animals classed as ***Ectotherms*** are able to change their colour. An ectotherm cannot generate its own body heat like mammals and birds. This group of animals includes reptiles, frogs, cephalopods (including species of squid, octopus, cuttlefish, and nautilus), insects, crustaceans and fish. Colour changes happen because of how light is absorbed and reflected by the chemical pigments in the cells of these creatures.

Reasons for the ability to colour change are mainly to camouflage and protect the animal from dangers such as predators, to assist with hunting prey, or to communicate warning and mating signals to other creatures. Colour change can also help an animal regulate its body temperature. For example: a lizard may be able to change to a darker colour that absorbs more lightwaves from the sun to warm itself.

There are different types of colour change in ectotherm animals, and these can be triggered by different processes in ***chromatophores*** (cells that can produce colour). Some of these processes are physiological – the changes in chromatophores are controlled by muscles and pigment sacs. Others are caused by crystal structures in the cells which can reflect different light wavelengths.

Watch this video to learn about the complex way chameleons and other animals can change their colour (4:28 minutes)

Media atribution: Chameleons are Masters of Nanotechnology by Reactions on YouTube

Learn more from this online resource.

# Colour chemistry 2: photography and chromatography



Figure 2.33. Daguerrotype photographic image by Louis Daguerre, 1837. Image attribution: Louis Daguerre creator QS:P170,Q131405, Daguerreotype Daguerre Atelier 1837, marked as public domain, on Wikimedia Commons

## Photography

The section on Optics in this resource explains how cameras work to project an image into the device using lenses and a camera obscura. In digital devices, the image is captured and saved as a digital image file, but originally, in traditional photography, the image was captured and fixed onto a light-sensitive film, which could then be used to reproduce multiple images.

Converting the image that appears in the camera to something that is printed on paper requires multiple chemical processes. An introduction to chemical photography is explained here...

## Black and White photography

Black & white photography was invented before colour photography. It involves the use of light-sensitive **silver halide crystals** that form an emulsion on celluloid or plastic film with gelatin (originally, glass plates were used). The energy from the light waves that enter the camera and hit the film causes a chemical reaction with the silver halide. Creating silver halide crystals for photographic film is a complex chemical process making them photosensitive to all visible wavelengths of light

The more light that comes into the camera and hits the light-sensitive film, the greater the reaction in the silver halide crystals, which creates silver ions. The grains of silver halide create an image by reacting to the different amounts of light hitting different parts of the film and creating different quantities of silver ions. However, you can't see the image on the film until the film is 'developed' because it's still light-sensitive and the image is not yet stable.

Developing photographic film is another process where chemicals are used to turn the silver ions into silver metal – more light produces more silver and a darker, opaque area on the film. Less light produces a more transparent area on the film. This process creates what we call a **negative image** – light parts of the image appear dark and dark parts appear light. Once the film is developed, the chemical processes must be stopped and fixed so that the silver halide crystals are removed and only the silver metal is left. Once developed, you can take the film out into the light and see the negative image.

So how do we create a positive image from the negative film? Another chemical process is used with light-sensitive paper, which also contains silver halide crystals held on the paper with a gelatinous emulsion – like the photographic film.

A white light is shone through the negative film onto the paper, activating the silver halide to create more silver ions on the paper. You can't see the image on the paper until it is developed in a bath of chemicals that turn the silver ions into silver metal – which oxidises and shows up as dark areas on the paper. The process is then stopped and fixed – just like the film. This is how we get a positive image on a photograph – the clear areas on the negative let more light through and create darker areas on the paper. The dark, opaque areas on the film let less light through and therefore create lighter areas on the photographic paper.

Learn more about the history of photography and Daguerre(Figure 2.33) who was one of the first photographers to create stable photographic images.

## Colour photography

Colour photography is more complex than black and white. It is a subtractive colour process. Colour film uses silver halide just like black and white photography, but the colour film has three layers of emulsion, each with a different light-sensitive dye mixed with silver halide that is sensitised so that each layer only captures either red, green or blue light. To create a colour negative image, the dyes form the complementary or opposite colour:

- Red-sensitive layers have cyan-coloured dye.
- Green-sensitive layers have magenta-coloured dye.
- Blue-sensitive layers have yellow-coloured dye.

The film is developed, and the silver halide is removed in this process, leaving only the coloured layers on the film. Printing to colour photographic paper is a similar process to printing black and white, turning a negative colour image into a positive colour image, but the paper has three layers of emulsion, just like the colour film, sensitive to red, green and blue light, which creates a chemical reaction turning the dyes into cyan, magenta and yellow dyes (Figure 2.34).

*Note: there are also special colour films that create a positive image instead of a negative one, and these were used in* ***slide projectors*** *– a technology not often seen today since the advent of digital photography and projections.*

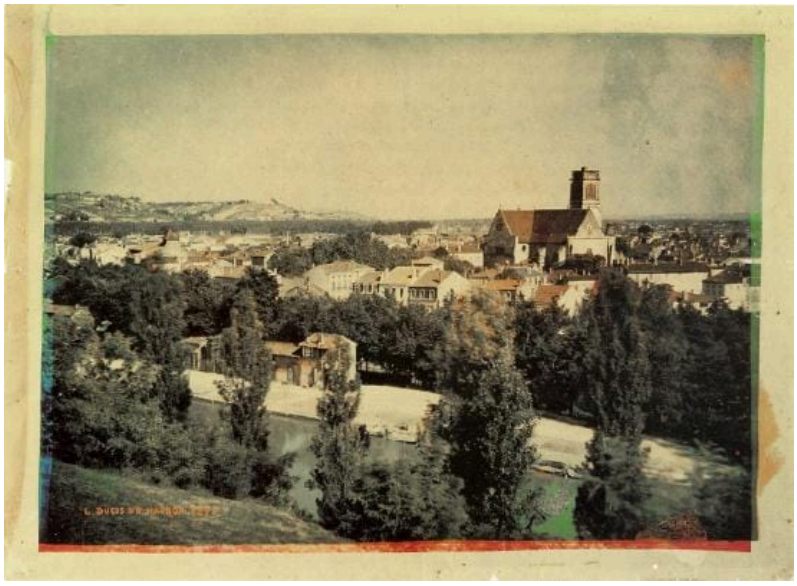


Figure 2.34. Early colour photograph of Agen, France by Louis Ducos du Hauron, 1877. Image attribution: Louis Ducos du Hauron (1837 – 1920), Duhauron1877, marked as public domain, on Wikimedia Commons

Learn more about the history of colour photography.

# Chromatography

Chromatography is a chemical process that is used for separating the different parts of a mixture – a liquid or gas substance that has multiple ingredients. The name means 'colour writing' from the Greek words *chroma* and *graphe*. This process was originally used to separate different coloured pigments that were all mixed together – a technique also used to create coloured dyes for making textiles and carpets.

Chromatography today isn't specifically about separating colours. It's used to separate all kinds of substances.

The way it works is by dissolving the mixture in some kind of solvent which could be gas or liquid **– the mobile phase –** and then using another material which could be a liquid or solid – **the stationary phase –** to separate the parts of the mixture. Because the different substances in the mixture travel along the stationary phase material at different speeds, they get separated from each other and form different bands.

If you're trying to separate colours from a liquid mixture by using paper, for example, you would see different stripes of colour appearing as some colours move faster along the paper and so move closer to the top, and others move more slowly, so remain closer to the bottom – like a rainbow of different coloured stripes. Figure 2.35 shows an example of this using paper and a liquid solution to show the chromatography of chlorophyll.

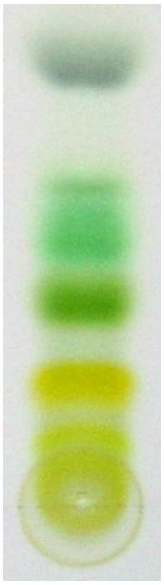


Figure 2.35. Chromatography of chlorophyl. Image attribution: Flo~commonswiki, Chromatography of chlorophyll – Step 7, CC BY-SA 2.5 on Wikimedia Commons

A very simple way to see this process work is to use black ink (the mixture), water (the solvent) and absorbent paper (the stationary phase material) to separate the colours from the ink mixture. See the activity details below – you can try this experiment at home.

Learn more about chromatography:

- Ask a Scientist: What is Chromatography?
- Explain That Stuff: Chromatography

**Activity: paper chromatography experiment**

You can make your own science experiment at home with a few simple materials to see how chromatography works in practice.

Watch this video for details and try your own experiments:

Media attribution: Paper Chromatography | Fun Experiments and Clear Explanations, Science Buddies on YouTube

# Colour chemistry 3: universal indicator and diagnostic tests



Figure 2.36. Test tubes containing solutions of pH 1–10 colored with an indicator. Image attribution: Alvy16, PH scale 3, CC BY 4.0

## Universal indicator

We can identify the acidity levels (pH value) of many substances with colour testing.

## What is pH?

**pH**, originally meaning “potential of Hydrogen”, is a numbering system used for measuring the acidity of substances dissolved in a water solution. A low pH value has a higher **acid** content. A high pH value indicates a higher **alkaline** or **basic** substance. Water has a neutral pH value of 7, which is why it’s a good solution to test the pH of other substances dissolved in it. For example, lemon juice can have a pH of around 2 – which is very acidic. Lemons have a high quantity of citric acid in them, which is why they have a low pH value. The detergent you use to wash your dishes is alkaline or basic, so it might have a pH value of around 8.

Learn more from this book Acids and Alkalis by Denise Walker.

To test the pH level of any solution, a universal indicator is used. This can be in the form of a paper tape that you dip into your solution, or it could be a liquid that is added to a solution. The universal indicator contains a set of chemicals that change colour depending on the amount of acid or base substances in the solution (Figure 2.37). They work by producing extra protons depending on how acidic or alkaline the solution is, which in turn emit photons with different wavelengths.

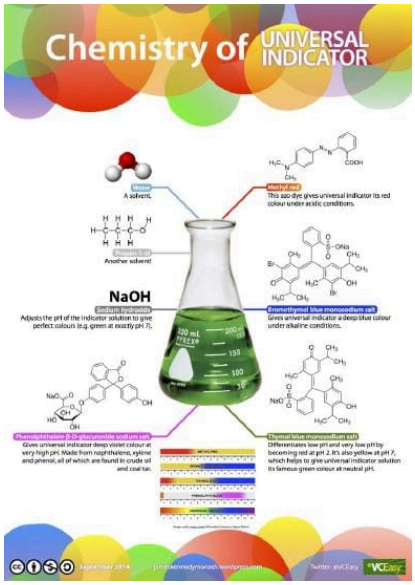



Figure 2.37. Chemistry of Universal Indicator by James Kennedy Monash. Image attribution: Chemistry of Universal Indicator by James Kennedy Monash, Creative Commons licence Attribution-Non-commercial-ShareAlike-4.0, select image to enlarge.

## Indicators in Nature

**Hydrangeas** are flowering plants that can grow flowers in a range of colours, including white, pink, purple and blue. Did you know that Hydrangea flowers can change their colour depending on the acidity of the soil? You can turn your pink hydrangea flowers blue by adding an acidic chemical like aluminium sulphate to your plant's water (Figure 2.38). The roots absorb this chemical, and the flower petals act as a natural indicator, turning from pink to blue if the soil pH level is more acidic than alkaline (basic).



Figure 2.38. Blue hydrangea flowers. Image attribution: photograph by Lisa Cianci, Creative Commons licence Attribution-Non-commercial-ShareAlike-4.0

You can also use **red cabbage** as an indicator by making a solution with chopped-up leaves and water. Red cabbage contains a water-soluble pigment called **anthocyanin**, which turns red if mixed with an acid substance and blue/green if mixed with an alkaline/base substance.

There are other plants that have anthocyanin and can also be used in the same way. Can you find three other examples?

Learn more about acids and bases.

You can buy universal indicator online and do your own experiments with substances around your home to see which are acids and which are bases, or you can make your own indicator with red cabbage. You can start by testing foods, drinks and cleaning products around your home. Is your tap water a pH of 7? If not, it might have other chemicals in it. See the activity below for instructions on making your own red cabbage indicator.

**Activity: make a red cabbage indicator**

You can make your own **indicator** at home with a red cabbage and a few simple materials to test the pH of different substances.

Watch this video for details and try your own experiments:

Media attribution: Test asides with home-made pH indicator, BBC Earth Lab on YouTube

## Diagnostic medical tests

Have you ever wondered how a pregnancy test or a COVID Rapid Antigen Test (RAT) works? How do the coloured lines appear on the test strip?

A pregnancy test uses chemicals that change colour when they come into contact with certain enzymes that attach to antibodies. When you are pregnant, your body produces a hormone called human chorionic gonadotropin (hCG). This hormone is excreted by the kidneys into urine – so putting urine on the test strip will start a chemical process that tests for the hCG hormone. The test strip contains an enzyme that will attach itself to the hCG hormone in the urine. As the urine moves along the test strip, there are two lines that can change colour – one will change colour and become visible if it comes into contact with the enzyme that is attached to the hCG – the test line. Another line will change colour and become visible if the enzymes not attached to hCG come into contact with it – the control line.

Two lines are needed to ensure the test has worked correctly because if there was only one line, it could show a false-negative result if the test didn't work properly.

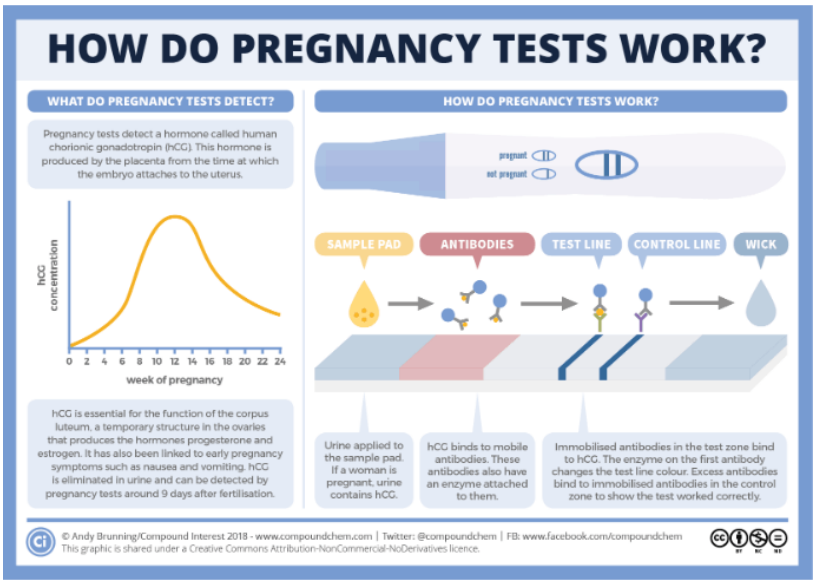



Figure 2.39. How do pregnancy test work? Image attribution: Compound Interest – How do pregnancy tests work? Select image to enlarge.

Watch this video that explains how a **COVID rapid antigen test** works:

Media attribution: Chemist Breaks Down How At-Home Covid Tests Work | WIRED by Wired on YouTube

# Colour chemistry 4: fireworks



Figure 2.40. New Year's Eve Fireworks on Sydney Harbour. Image attribution: Rob Chandler, New Year's Eve on Sydney Harbour, CC BY-SA 2.0 on Wikimedia Commons

## How do they make different coloured fireworks?

Fireworks were recorded as originating from China in the 8th Century CE. It is said that explosive **black powder** was accidentally invented by alchemists who mixed potassium nitrate (also called s*altpetre*), sulfur and honey together while trying to create the *elixir of life*. The mixture exploded when heated – this is called an **exothermic chemical reaction**. Recipes for this explosive mixture eventually made their way across Asia and the Arabic world to Europe, which is where fireworks as we know them today were first created.

The explosive part of fireworks is gunpowder (black powder) which is now made from saltpetre, sulfur and charcoal. The reason fireworks can appear to have a range of colours is because different chemical compounds are used, which are mostly metals that burn very brightly, and these are coated in gunpowder. Exploding gunpowder burns the chemical compounds, which causes electrons in the compounds to get excited and release excess energy as photons (light). These photons have different wavelengths in the visible spectrum depending on the energy of each chemical's electrons, and this is how we see fireworks as different colours (Figure 2.41).

Somecolours, like blue fireworks, are harder to make because the chemical compounds are not stable. Purple is also difficult because it's made from a mixture of red and blue compounds.

**Fireworks colours and their chemical compounds:**

- **Red – Strontium salts**
  Strontium Nitrate, Strontium Carbonate and Strontium Sulfate
- **Orange – Calcium salts**
  Calcium Carbonate, Calcium Chloride and Calcium Sulfate
- **Yellow – Sodium salts**
  Sodium Nitrate, Sodium Oxalate and Cryolite
- **Green – Barium salts**
  Barium Nitrate, Barium Carbonate, Barium Chloride and Barium Chlorate
- **Blue – Copper salts**
  Copper (I) Chloride, Copper Carbonate and Copper Oxide
- **Purple – Combination of Red and Blue**
  Strontium and Copper compounds

- **Silver – white hot metals**
  Magnesium and Aluminium
- **White – burning metal**
  Magnesium, Aluminium and Titanium

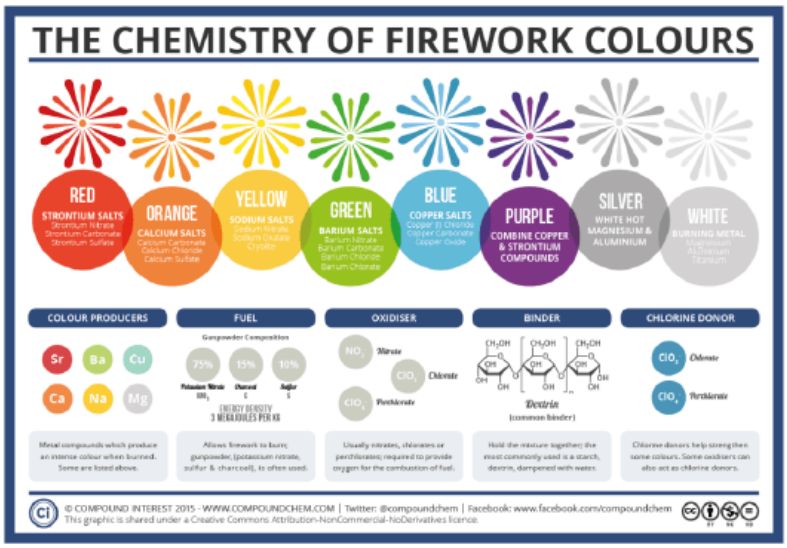



Figure 2.41. Image attribution: this image shared from www.compoundchem.com, Creative Commons Attribution-NonCommercial-NoDerivatives licence, © Compound Interest 2015. Select image to enlarge.

## Test yourself: colour chemistry

### A multiple choice quiz to test your understanding of colour in chemistry

### (5 minutes or less)

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# 2.4: The Eye- How We See Colour

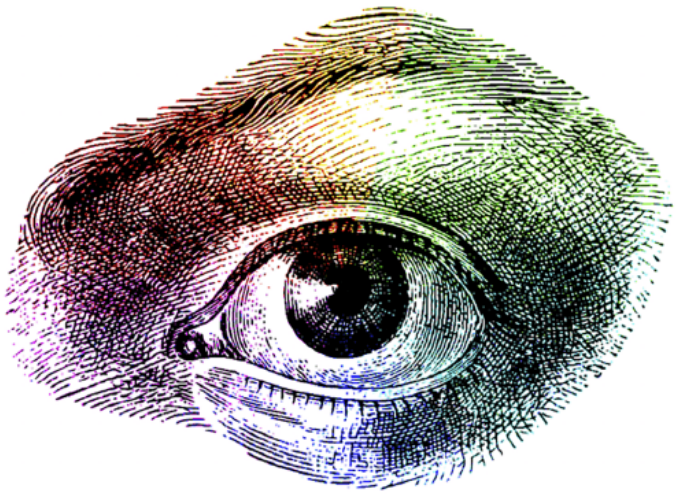
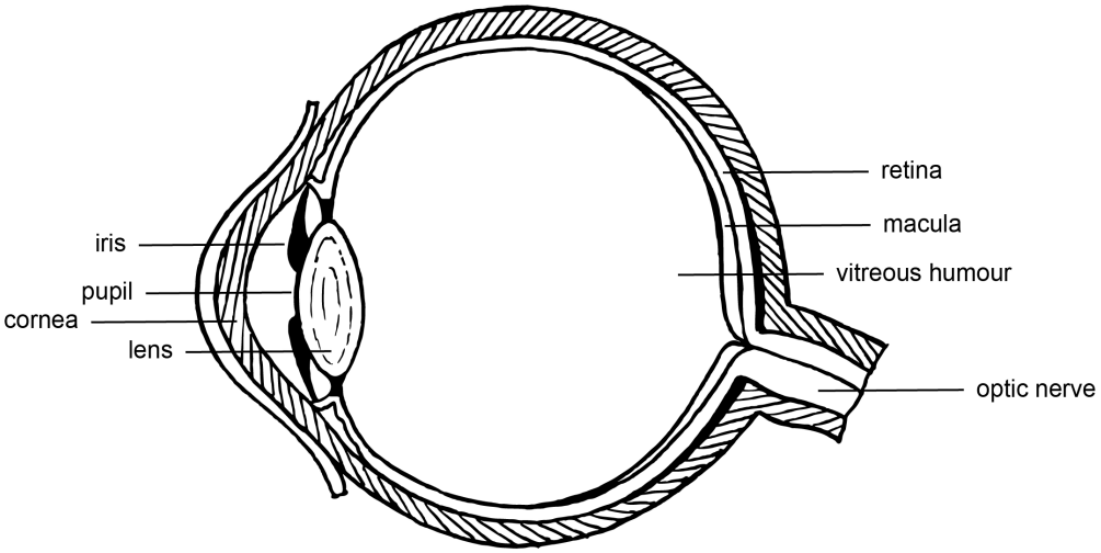


Figure 2.42. Image attribution: image by Lisa Cianci, adapted from an engraving from *Meyers Conversations-Lexicon*, 1897, CC-BY-NC-SA

## Anatomy of the human eye




### Anatomy of the human eye

The eye works like a Camera Obscura – a small, almost spherical chamber (Figure 2.43) where light enters via the **cornea** and through a small hole (the **pupil**). The **iris** controls how much light enters the eye through the pupil. Light then passes through a **lens** which can change shape to focus the image. The image is projected through a transparent, gel-like substance (**vitreous humour**) to the back of the eye (**retina and macula**), which contains light-sensitive cells. The retina is connected to the brain via the **optic nerve**.

Just like in a camera obscura, the image projected onto the retina is upside-down and reversed, but we learn to interpret the

visual input the right way around.

What is perhaps the most interesting part of eye biology for colour theorists is how the cells in the retina are sensitive to light and colour and how this information is transmitted to the brain.

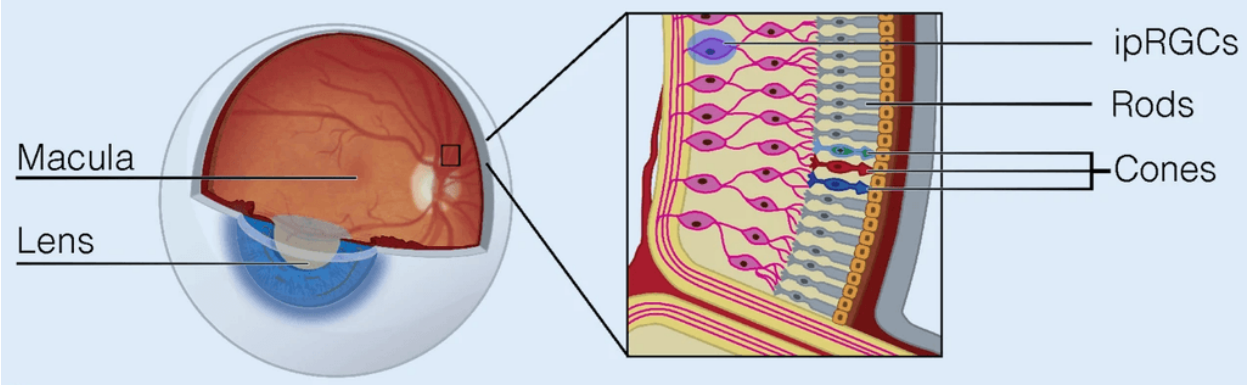



Figure 2.44. Overview of the retina photoreceptors. Schematic view of the eye with the retina at the back of the eye (the fundus), containing cones, rods and the intrinsically photosensitive retinal ganglion cells (ipRGCs) expressing the photopigment melanopsin. Image by Christine Blume, Corrado Garbazza & Manuel Spitschan on Wikimedia Commons, licensed under CC BY 4.0.

## Retinal cells

Photons of light falling on the light-sensitive cells of the retina are converted into electrical signals that are transmitted to the brain by the optic nerve (Figures 2.44 and 2.45). The brain interprets this information as vision.

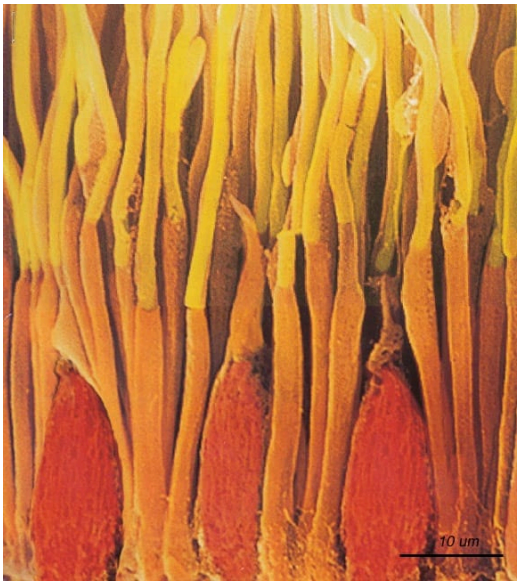



Figure 2.45. Photographic image of rod and cone cells of the retina. Image by: Helga Kolb, Rrods and cones of the primate retina, CC BY-SA 4.0, on Wikimedia Commons

There are three types of cells in the retina that convert light energy into electrical energy.

**Rods**
These cells respond to low-intensity light and help us to see low-resolution, black-and-white images – it's why we can still see things in very low light. Animals that can see in the dark have more rods than we do.

**Cones**
These cells respond to high-intensity light and enable us to see high-resolution, coloured images.

**Photosensitive ganglion cells**
These cells respond to a full range of light intensities and help the eye adjust the amount of light that enters the eye and reaches the retina. Ganglion cells help define what we see – especially when it comes to recognising edges and borders.

Ganglion cells have also been discovered to regulate the hormone **melatonin**, and the **circadian rhythm**, which both help us have a regular sleep cycle. This is why it's not good to look at your screen devices late at night because the blue light stimulates these cells and can inhibit natural sleep processes.

## Cones – how do they detect colour?

There are two current theories about how cone cells detect colour, and they can both help us understand how colour vision works.

### Trichromatic colour vision theory

Trichromatic theory of colour vision tells us that we have three different types of cone cells in our eyes – one each for red, green and blue. These cells are stimulated by different ranges of light waves, and it's the combination of information from all three types of cells that makes up the millions of colours our brains can perceive. However, it doesn't fully explain phenomena like how we can't see "yellowish-blue" or "reddish-green".

### Opponent and complementary colour theories

The opponent process theory of colour tries to describe how the cone cells are more complicated than just red, green, and blue receptive. Instead, the cones have opposite reactions. Originally the opponent pairs were thought to be red-green, blue-yellow and black-white. But in recent times, complementary colour theory shows us that the three "opponent" pairs are red-cyan, green-magenta, and blue-yellow.

These are very complex theories that attempt to explain all the weird things that we see, like afterimage optical illusions. None of the theories described here are able to explain all of our visual experiences, but research continues to explore how our eyes and brain work together to see colour.

You can test the afterimage and complementary colour theory now – all you need is a white piece of paper or wall and the image in Figure 2.46.

> **Activity – afterimage optical illusion**
>
> Stare at the image in Figure 2.46 for 20 seconds (red square with a smaller white interior square). Then quickly look at a piece of white paper or a white wall and stare at the white area for a while.

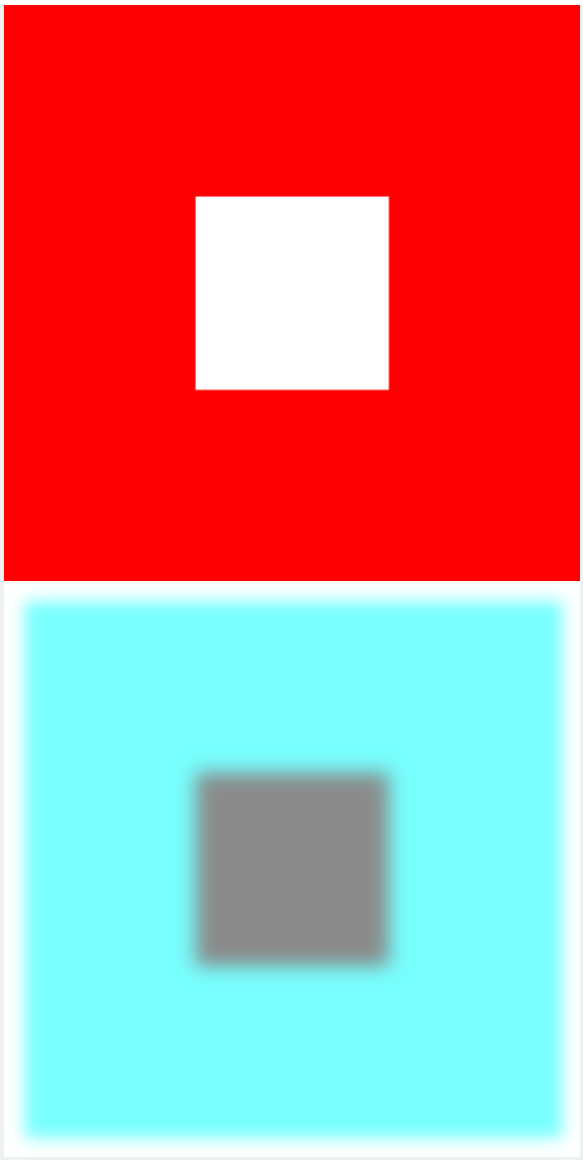


Figure 2.46. Red Square with white interior. Image attribution: Red Square with white interior by Lisa Cianci, Creative Commons licence CC BY-NC-SA 4.0What you might briefly see is a faint afterimage of the opposite colours – a blurry cyan square with a smaller dark square inside it, as in Figure 2.47.This optical illusion can be explained by opponent theory. By staring at the red square for a long time, the cone cells become weaker at detecting red (or transmitting the red vision signal to the brain). Therefore, when you look away to the white paper, the white colour doesn't register properly as white, it leaves out the red part of white light, and you only see the opposite colour – cyan.After a while, this illusion fades and your vision will return to normal.Figure 2.47. Red afterimage: cyan square with grey interior. Image attribution: Red afterimage: cyan square with grey interior by Lisa Cianci, Creative Commons licence CC BY-NC-SA 4.0

[Learn more about opponent process on Wikipedia]

## Chimerical colours – impossible or imaginary colours.

The afterimage in the experiment above is also known as a **chimerical colour**, after the mythical beast, the **Chimera**. Objects around us do not have imaginary colours, we use that term to describe colours we might see that are not part of normal vision. However, theoretically, there are mathematical descriptions of colours that are outside the visual colour space.

The cone cells in our eyes have sensitivities to short, medium and long wavelengths, and these sensitivities overlap a bit. We don't usually see colour with only one type of cone at a time – it's usually a mixture. An impossible colour might occur, for example, if

we only saw green with the medium-length cone – we might see it as an extremely intense green. Something outside of the range of the CIELAB colour space.

### Types of Chimerical colours (Figure 2.48)

#### Stygian

Stygian colours are both dark and impossibly saturated. You could see “stygian blue” by staring at bright yellow (to cause a dark blue afterimage), then looking at a deep black surface. The blue afterimage is viewed over the black, and simultaneously as dark as the black.

#### Self-luminous

The experiment using Figure 2.46 is an example of self-luminous colour. The cyan afterimage is self-luminous and might appear even brighter than the white paper you are looking at.

#### Hyperbolic

This is an impossibly highly saturated colour (hyperbolic means exaggerated). You can try an example of this more intense and highly saturated colour by changing the experiment using Figure 2.46.

Try the experiment again, and this time, after you focus on the red square (Figure 2.46), look straight at the blurry cyan square below it (Figure 2.47). You should see an impossibly bright cyan – brighter than any colour you could see with normal light.

#### Eye fatigue template for impossible colours

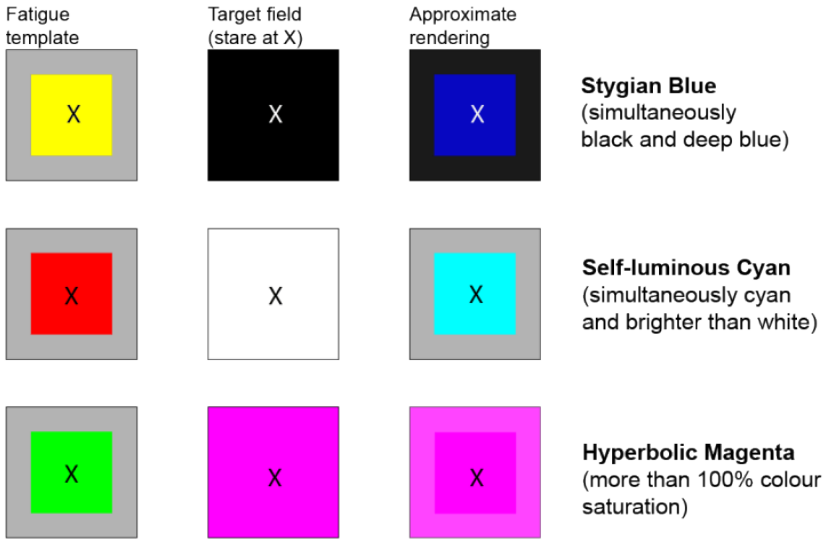



Figure 2.48. Diagram for viewing “impossible” chimerical colours that are only accessible via fatigue effects in the human eye. Image attribution: Lisa Cianci, adapted from an image by Zowie at English Wikipedia, Chimerical-color-demo, CC BY-SA 3.0, on Wikimedia Commons

# How the brain interprets colour information

## Binocular vision

As stated in the Optics section on 3D glasses, we have two eyes, yet only see one image. The brain processes a lot of visual information that comes from two sources at the same time, and it puts this all together to make one image that allows us to interact with the world around us. There are many complex processes happening very quickly, all at once. It is thought that around

40% of the brain's function is used for processing vision.

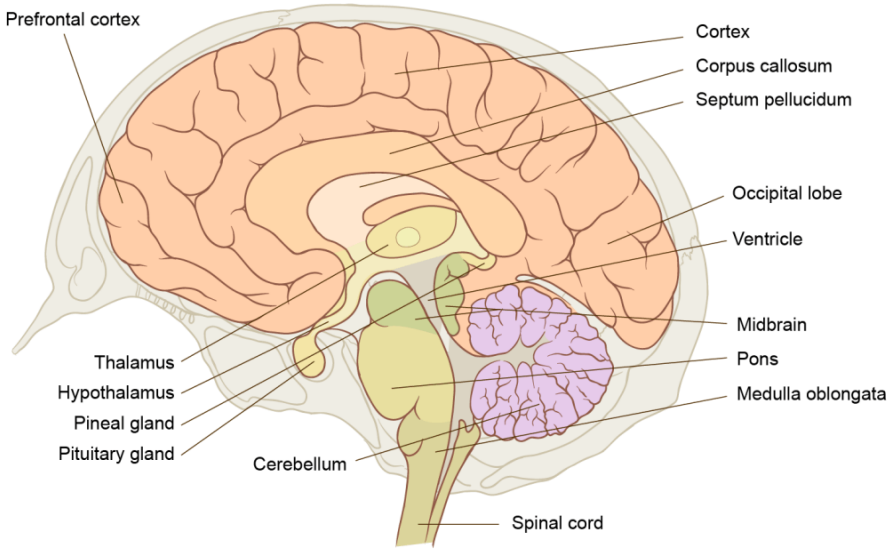



Figure 2.49. Human brain, adapted from an image by Patrick J. Lynch via Wikimedia Commons, licensed under CC BY 2.5.

The optic nerve connects the retina at the back of the eye to a part of the brain called the **thalamus** (Figure 2.49). The thalamus processes the information from both eyes and sends it to another part of the brain – the **visual cortex** in the **occipital lobe**. The visual cortex contains cells that detect different kinds of visual information, like colour, form and movement. It puts all of this information together into what we perceive as an image. This image is then sent to the **prefrontal cortex**, which processes that information along with other information, like emotions and memories. This all helps us to not only see but to understand what we are seeing and make sense of objects, movement, depth perception, light and colour.

Watch this video for more information

Media attribution: How Your Eyes Make Sense of the World | Decoder, National Geographic, on YouTube

The way we perceive colour is subjective and can depend on how we are seeing the environment, the lighting, and the positioning of colours next to each other. This relates to the content in chapter 1, section 1.3 colour aesthetics, and the creative experiments done by artists and theorists like Johannes Itten and Josef Albers.

## Read this article: Colour is all in our heads!

## Is Magenta a real colour?

There was a recent online article claiming that magenta isn't a real colour because it doesn't exist on the colour spectrum. Of course, you could say that about any colour that isn't visible on the spectrum as a single wavelength (like brown, for example) because our brains interpret many light wavelengths from the visible spectrum and mix the wavelengths for red and blue to make a colour that we see as magenta.

Read this *Ars Technica* article to understand the whole story.

### Optical illusions

Optical illusions can tell us a lot about how our brains make sense of the light waves that enter our eyes. One of the most common illusions relates to relative colour and lightness. A colour can look completely different depending on what's next to it.

The animation in Figure 2.50 is a good example of the concept. The moving square does not change colour at all, but our perception of the colour changes as the background colour blends from pink to green.

[Content couldn't be imported.]

It also helps explains recent viral social media phenomena like the striped dress – is it blue and black or white and gold?

Learn more about optical illusions here and watch this video for more information.

Media attribution: Optical Illusions show how we see | Beau Lotto, Ted on YouTube

This video discusses how what we see is subjective – can you really trust what you see?

Media attribution: Everything You See is Fake | Fractured Realities, BBC Earth Lab on YouTube

## Colour blindness

Colour blindness is usually a genetic condition that you are born with. It is often a hereditary condition, which means that it is passed down from your parents, but there are other ways that people can become colour blind, including through disease or injury.

Colour blindness affects colour perception – most people with colour blindness can see clearly and can see some colours, but not all colours of the visible spectrum. Some forms of colour blindness affect more males than females. For example, the gene mutation responsible for red/green colour blindness is carried on the X chromosome. Males only have one X chromosome, and females have two, which means that females are less likely to have colour blindness because even if they have the mutated gene on one X chromosome, they have another one which may not have the mutation.

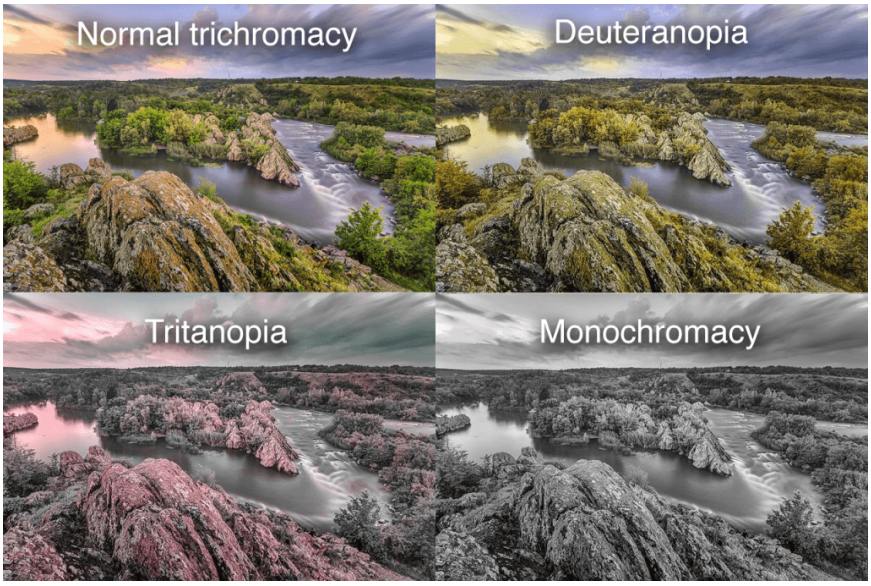



Figure 2.51. Comparisons of vision differences: normal trichromacy, deuteranopia, tritanopia and monochromacy. Image attributions:Q-lieb-in, Вечір на “інтегралі” – річка Південний Буг, CC BY-SA 4.0, Tohaomg, Deuteranopia sight, CC BY-SA 4.0, Tohaomg, Tritanopia sight, CC BY-SA 4.0, Tohaomg, Monochromacy sight, CC BY-SA 4.0

### Types of colour blindness

Normal colour vision is called **Trichromacy** (*tri* means three, *chroma* means colour) where all three types of cone cells function properly.

**Anomalous trichromacy** is where normal trichromatic vision doesn’t work properly (Figure 2.51). The cones might still perceive light, but they are not perceiving the right range of light wavelengths. This can also have different levels of severity. Some people with anomalous trichromacy might not have trouble seeing a full range of colours, while others will have noticeable vision differences.

Types of anomalous trichromacy

- **protanomaly** – reduced sensitivity to red light
- **deuteranomaly** – reduced sensitivity to green light
- **tritanomaly** – reduced sensitivity to blue light (the rarest form)

**Dichromacy** (*di* means two) is where only two types of cone cells function properly. This means that there are parts of the visible spectrum that can't be perceived by the brain.

Types of Dichromacy:

- **protanopia** – unable to see red light
- **deuteranopia** – unable to see green light
- **tritanopia** – unable to see blue light (the rarest form)

A common type of colour blindness is red/green colour blindness, but it's more complex than not being able to see red or green. The type and severity may be different for each person. Learn more about red/green and other types of colour blindness here.

#### Monochromacy (achromatopsia)

Monochromacy (*mono* means one) is where no colour can be seen at all – everything appears to be in black and white with shades of grey. This form of colour blindness is rarer than Dichromacy (Figure 2.52).

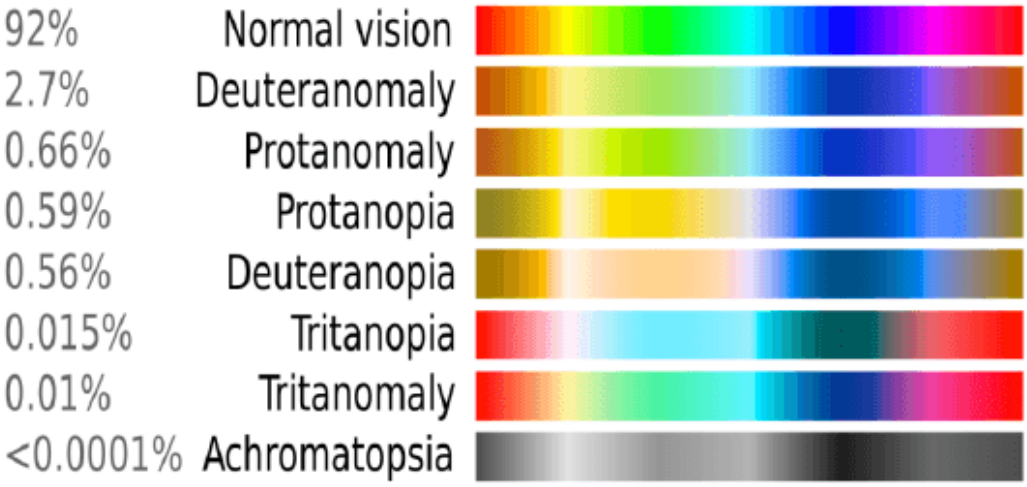



Figure 2.52. A comparison of the visible colour spectrum in common types of colour blindness. diagram. Image attribution: SyntaxTerror, Color blindness, marked as public domain, more details on Wikimedia Commons

Watch this video for more information about colour blindness:

[Content couldn't be imported.]

## How do I know if I am colour blind?

Some people may not be aware that they have colour blindness – especially if it's not severe. Other people may find out early or late in their lives. If you think you might be colour blind, there are websites with online tests that you can try for red/green colour blindness, but not for blue colour blindness.

You can see your doctor if you think you may have colour blindness or vision difference. Professional testing is recommended for certain professions like pilots, astronauts, truck drivers, and designers or creative people working with colour. One of the disadvantages of colour blindness, apart from not seeing a full spectrum of colours, is understanding common communication devices, like traffic lights, which are red, amber and green.

**Activities – test yourself**

**The Ishihara 38 plate CVD test** is a popular test you can try now for red/green colour blindness (Figure 2.53). It uses circles with coloured dots that display numbers or lines. If you have a red/green colour vision problem, you may find it difficult to see the numbers and lines in many of these circles.

**Ishihara Plate 9 – Can you see a number in this image?**

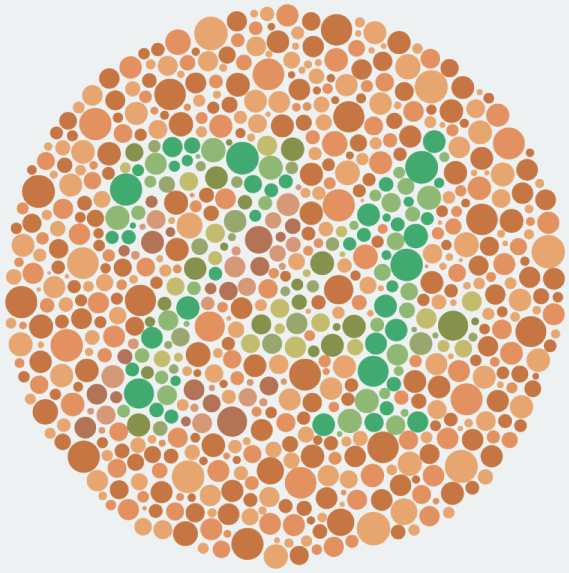


Figure 2.53. Ishihara Plate 9. Image attribution: Original: Shinobu Ishihara creator QS:P170,Q530761 Derivative work: Pbrks, Ishihara 9, marked as public domain, more details on Wikimedia Commons

**The Farnsworth-Munsell hue test** is for the arrangement of colours – whether you can see the slight differences in a gradient between two colours can tell you if you have a colour deficiency.

These resources contain information and self-test activities to learn more about colour blindness.

- ColourblindAwareness.org
- Xrite.com: color perception part 1
- Xrite.com: hue test
- ColorVisionTesting.com
- Color-blindness.com: Ishihara cvd test

## Vision difference: tetrachromacy and synesthesia

Not everyone sees the same colours or perceives the world around us in the same way. Here are two examples of vision difference:

### Tetrachromacy

**Tetrachromacy** (*tetra* means four and *chroma* means colour) is the name for having four types of cone cells in the eye to perceive colour. It is common in the animal world, but not normal in humans. However, some female humans are tetrachromats and can see a wider range of colours than normal trichromats.

Research is ongoing to determine how this works. One theory suggests that it's related to colour blindness, and the reason it only affects females is because they have two X chromosomes. If a person has one X chromosome with the mutant gene for colour blindness, and the second X chromosome is normal, then this might cause tetrachromacy. This theory speculates that if a person has two different kinds of red/green cone cells that detect different wavelengths of light, they will have the ability to see more colours. Some tetrachromats may also be able to see better in low light conditions.

Watch this video to learn about an artist with tetrachromacy:

Media attribution: Seeing colours nobody else can – Incredible Medicine: Dr Weston's Casebook | Episode 2 – BBC 2, BBC on YouTube

You can also read the BBC article here.

## Synesthesia and colour sensory perception

Synesthesia is a neurological condition where you experience one sense through another. An example of synesthesia is hearing music and seeing coloured shapes or for some synesthetes, associating certain numbers or words with particular colours. It's not only colour-related, though. For some people, hearing certain sounds causes tingling sensations in different parts of their bodies. There are many different kinds of synesthesia.

Synesthesia is a type of neurodiversity, and appears at a higher rate in people with other types of neurodiversity such as Autism Spectrum Disorder, or people who identify as transgender or gender variant. Quite a few visual artists and musicians have synesthesia – it's possible this *cross-wiring* of the senses can be a benefit to creative practitioners. Some people with synesthesia have incredible memories too, which could be due to how the brain associates sensory input and how it is stored in memory.

Two of the more common forms of synesthesia are:

- **Chromesthesia** – Sound to colour
- **Grapheme-colour synesthesia** – letters and numbers to colour

Watch this video for more information:

Media attribution: What color is Tuesday? Exploring synesthesia – Richard E. Cytowic, Ted Ed on YouTube

## Synesthesia and creativity

Visual artists from history who were known to have Chromesthesia (sound to colour) include: Wassily Kandinsky (Figure 2.54), Vincent Van Gogh, David Hockney, and Arcimboldo (he had vision and taste Synesthesia also).



Figure 2.54. Entwurf 2 zu Komposition VII by Wassily Kandinsky. Image attribution: Wassily Kandinsky artist QS:P170,Q61064, Entwurf 2 zu Komposition VII (Wassily Kandinsky) DSC1682, CC0 1.0 on Wikimedia Commons

Learn more from these links:

- Listening to Art by Alanna Irwin
- How synaesthesia inspires artists

**Contemporary artists with synesthesia**

- Melissa McCracken
- Carol Steen
- Sobrane Symcock

There are many popular musicians who also have chromesthesia – can you search the Internet and find some that you know about?

This synesthesia FAQ (frequently asked questions ) web page has some useful information if you want to learn more.

***Note**: A study that indicated more females have synesthesia than males may not be accurate due to the bias that more females would be likely to self-refer for the study.*[1]

1. Simner, Julia & Carmichael, Duncan. (2015). Is synaesthesia a dominantly female trait? Cognitive neuroscience. 6. 10.1080/17588928.2015.1019441.

# Accessible colour

Using accessible colour is important in the media and objects we interact with in everyday life. This enables the greatest number of people to see and understand what is communicated. As explained in the previous sections about vision difference, not everyone can see the same range of colour or light, and some people have other vision problems that make it difficult to see. This is particularly relevant for reading text and for viewing visual communications content like maps, diagrams, charts and infographics that present information in very visual and colourful ways.

If you are a designer working with print or digital media, knowing about accessibility and how to make sure your content is accessible is very useful for creating content that can engage with a wide audience, and promote values like equality and fairness in branding for products and services.

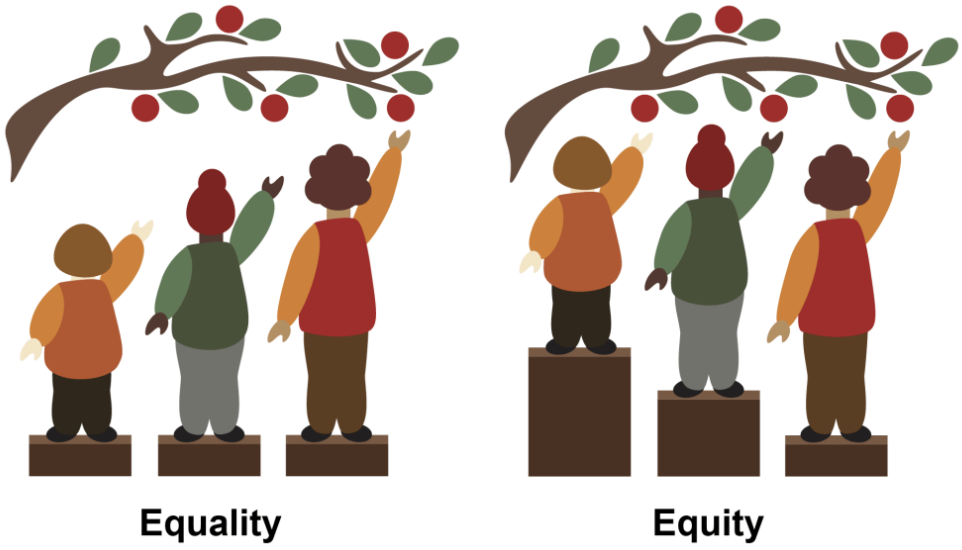



Figure 2.55. Equality and equity, by RMIT, licensed under CC BY-NC 4.0.

**Universal, Inclusive and Equity focused design – what are they?**

Universal, inclusive and equity-focused design are concepts and principles that can assist you as a designer. They can ensure you consider all user needs when creating all kinds of products, buildings, online content, and anything that goes through a design process.

- **Universal** design principles are about making sure your design is accessible to everyone.
- **Inclusive** design principles include focusing on user groups that might have special needs or who might be otherwise excluded.
- **Equity-focused** design principles are proactive in working with user groups who are minorities or have special needs to create solutions and form ongoing relationships with those communities.

You can use one or more of these as part of your design methodology. Read this article for more information: **Universal, Inclusive and Equity-Focused Design: Why They are Critical for Your Website**.

## What does this mean for accessible colour in art and design?

Planning your colour schemes and relationships for creative work should involve careful consideration of accessibility issues that might impact your audience. Examples of accessible colour for both print and digital media include:

- using appropriate contrast (light and dark) in text and background colour
- using colour combinations (hue, saturation and lightness) in text and graphics that people with colour blindness can see
- having enough space around colour elements so they are not confusing to understand
- having text at the appropriate size and weight, or allowing resizable text
- including warnings for moving or flashing colours and images that can trigger seizures in some people.

Example of good and bad colour combination for accessibility

| Red text is bad on black | Yellow text is good on black |
|---|---|
| Cyan text is bad on orange | Black text is good on orange |
| Magenta text is bad on green | Black text is good on green |
| Green text is bad on blue | White text is good on blue |
| Grey text is bad on grey | White text is good on grey |

Figure 2.56. Examples of good and bad colour combinations for accessibility. Image attribution: image by Lisa Cianci, Creative

Commons licence Attribution-Non-commercial-ShareAlike-4.0. Select image to enlarge.

This Mozilla article gives a good overview of understanding colour accessibility for the Web.

The World Wide Web Consortium (W3C) has a Web Accessibility Initiative (WAI), which develops standards and support materials to help you understand and implement accessibility in your online content.

**Activities: using tools and resources for accessible art and design**

**Activity 1.**
**Try testing the colours of your own website or print graphics to see if they have good accessibility. If not, how can you tweak your colour palette to have more accessible text and graphics?**

There are many free online tools that you can use in your art and design work to check that the colour combinations you are using are accessible and comply with W3C standards. Most of these are checking foreground and background colour contrast for text and graphics. Here are three examples:

- Accessible web contrast checker
- Web AIM contrast checker
- Colour contrast checker

**Activity 2.**
**If you're planning an exhibition or creative event, whether online or in a physical space, make a checklist based on information in the resources listed here. You can work through each item in your checklist to ensure your event has the best accessibility you are able to provide. That might include things like the colour of signs and labels, easy-to-read instructions with adequate fonts, lighting, arrangement of artworks, etc.**

These links and resources for artists and designers can help make your creative work more accessible:

- Access Arts resources
- Accessible Arts -accessible exhibition design
- Tangled art & disability – resources
- Arts Access Victoria
- Creative User Projects (Canada)
- Centre for Inclusive Design
- The A11y Project – resources
- W3C standards – accessibility

**Activity 3.**
**Explore this topic further in a real world context in *Learning Lab Contextualised Content***

- Using accessible colour in design

## How animals see colour

The ideal gas law is easy to remember and apply in solving problems, as long as you get the **proper values a**



Figure 2.57. Spotted eagle owl. Image by jeanvdmeulen via Pixabay, licensed under CC0.

We humans are **mammals** and **primates**. The way we see colour is similar to many other animals. However, there is a wide range of colour vision in the animal kingdom, and many different kinds of eyes or "vision systems". This is due to animals' biological makeup, environment, and evolutionary history.

This page gives a short introduction to some of the weird and wonderful ways living creatures have evolved over millions of years to detect light and colour, and why it is useful to have colour vision. Studying colour vision in the animal world helps us understand visual systems and could lead to new discoveries in fields such as optics, chemistry and biology.

**Topics covered on this page**

- Primates and other mammals
- Birds, reptiles and sea creatures
- Insects, arachnids and other creepy crawlies

As explained in other parts of this resource, colour is not a fixed attribute of an object. Colour is a property of the "visual system" of the animal that sees it. The same light wavelengths reflected or emitted from an object can be seen differently depending on the anatomy of an animal's vision.[1]

## Primates and other mammals



Figure 2.58. Monkey's eyes. Image by a_m_o_u_t_o_n via Pixabay, licensed under CC0.

Primates mostly have good **trichromatic** colour vision, and humans may have the best colour vision of all primates. Most mammals have a mixture of **rod** and **cone** cells in the retina of the eye – just like humans – but the amounts of each type of light-detecting (**photoreceptive**) cells may differ between species. It is thought that being able to see colour is an advantage when searching for food. Being able to tell the difference between ripe (red and orange) and unripe (green) fruit on trees and plants, for example, makes it much easier to find things to eat.

Many mammals like cats, dogs, rabbits, cattle, sheep, and goats can only see a small amount of colour. These animals are mostly **dichromats** (they can only see two colours) and may only see pastel shades of blue and yellow. This means they have **protanopia** (red–green colour blindness).

Some mammals (like cats and wolves) have evolved so that their eyes contain more rods than cones, allowing them to see and hunt in the dark. It's not much use having good colour vision in the dark (as explained in Why are things different colours? in this resource), but having lots of rods that can perceive subtle differences between light and dark is much better for detecting the movement of prey in dark environments.

Some sea mammals, like dolphins, can detect blue light very well – which is useful when underwater, but cannot differentiate between colours at all. Dolphin eye lenses can change shape to be able to see well both above and below water – they can do something called "spy-hopping", where they raise their heads above water vertically to see their surroundings , accessed 12/01/2023">[2].

## Birds, reptiles and sea creatures

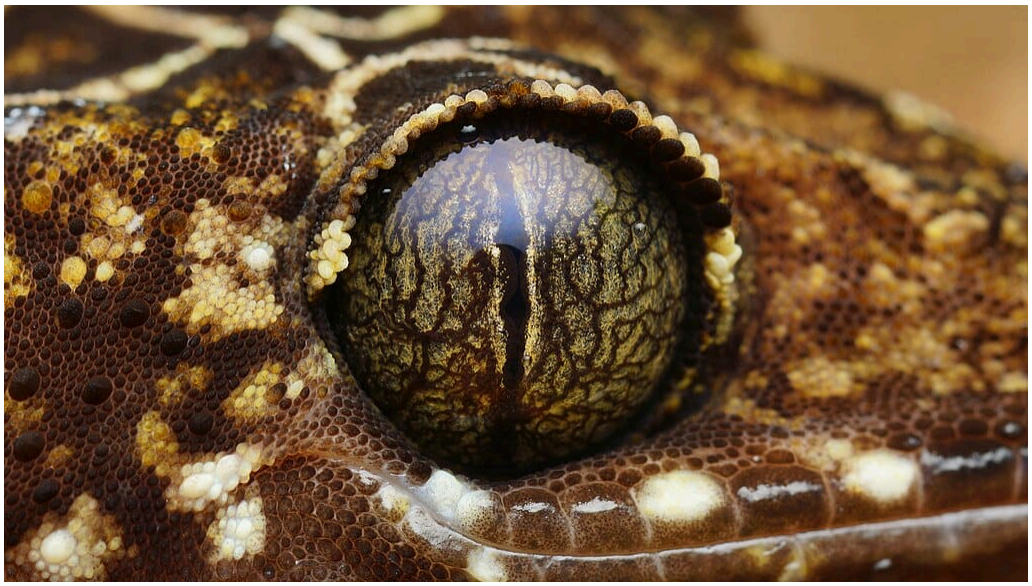


Figure 2.59. Banded forest gecko eye. Image by Kean Leng Ang via Wikimedia Commons, licensed under CC BY 4.0.

Birds of prey, such as eagles and hawks, have excellent colour vision, with four types of cone cells (**tetrachromacy**), allowing them to see the visible spectrum plus ultraviolet light, which we humans cannot see. This ability helps these birds to locate prey from great distances. For other birds, tetrachromatic colour vision makes it easier to locate specific flowers, nectar and fruits, and is important in mating behaviours. Pigeons have five types of cone cells (**pentachromacy**), but owls, as nocturnal predators, have very little colour vision. Early research suggested that owls were completely colour blind, relying only on highly sensitive rod cells to detect light and dark. However, more recent studies have found that owls do have some colour vision. They have the ability to see ultraviolet at night and most likely do see some the visible spectrum during the dayUV-sensitive cone opsin and red oil droplets, but see UV light at night: Retinal transcriptomes and ocular media transmittance', Vision Research, Vol 158, Pages 109-119, https://doi.org/10.1016/j.visres.2019.02.005. (https://www.sciencedirect.com/science/article/pii/S0042698919300471), accessed 12/01/2023" data-quail-id="672">[3].

The gecko is a type of lizard that has a complex colour vision system, which has been the subject of many research studies. One of the most impressive features of gecko eyes is their excellent colour vision at night. Unlike many other lizards, which have only two types of cone cells (dichromacy), some gecko species have four types of cones (tetrachromacy), allowing them to perceive a wider range of colours.

Another interesting feature of gecko vision is the presence of oil droplets within the cone cells. These droplets act as filters, absorbing certain wavelengths of light and enabling a greater sensitivity to other wavelengths[4]. The exact function of these oil droplets in gecko colour vision is still not fully understood, but they are thought to play a role in improving the ability to tell the difference between colours, even in low-light environments.

Chameleons are well known for their ability to change colour, but they also have very good colour vision – possibly the best vision of all lizards. Chameleons have “double cones” and four types of single cone cells, but very few rod cells, which means they don’t see well in the dark. The cone cells also contain oil droplets like geckos. Chameleons can see a wider range of colours than humans can, including ultraviolet light, and their eyes can move and focus together or independently of each other (monocular and binocular vision). They can focus on objects at great distances because of the shape of their corneas and lenses. Chameleons (and certain other animals) also have a layer in their eyes called the **tapetum lucidum**, which reflects light and enhances their vision in low-light conditions.

Snakes do not have colour vision in the usual sense. They are able to distinguish between light and dark, but they cannot perceive different colours. However, some species of snakes have specialised receptors in **pit organs** on their faces that allow them to ‘see’ (or sense) infrared light, which helps them locate warm-blooded prey. This is not the same as photoreceptors in the eyes. However, it is a means of detecting wavelengths of electromagnetic radiation.

Octopuses and squids (cephalopod species) have good vision – although cannot detect colour. Their eyes are more similar to those of humans and other vertebrates than those of most other invertebrates, with a single lens and a retina that contains

photoreceptor cells. However, the way these photoreceptor cells function in cephalopods is quite different from that of humans and other vertebrates. They also have a unique type of photoreceptor cell called a **rhabdom** that helps to detect polarised light, which is important for things like communication, navigation, and camouflage. If you're wondering how colour changing octopus can detect colour in its surroundings to camouflage itself without seeing colour with its eyes, see this page: Colour chemistry 1: animals that can change colour (hint: they have special cells in their skin that can produce colour to mimic their environment)

In fish, the number and distribution of cone cells for colour vision vary depending on the species and the environment in which they live. For example, fish that live in shallow water with a lot of sunlight tend to have more cone cells than those that live in deeper water with less light. Some fish also have rhabdom cells that allow them to see polarised light, which they use for navigation and communication.

Crustaceans have a more complex visual system than fish, with a wider range of visual pigments and photoreceptor cells. Some crustaceans, like the mantis shrimp, also have a type of compound eye (like insects) called an **apposition eye**, which allows them to have high spatial resolution and sensitivity to small changes in light intensity. Mantis shrimp also have 12 types of cones – although these cones only show very narrow bands of light wavelengths, so they don't see more colours than we do. Like fish and cephalopods, crustaceans also have rhabdom cells that allow them to see polarised light, and are also used for navigation and communication.

## Insects, arachnids and other creepy crawlies



Figure 2.60. Robber fly eyes. Image by Opo Terser via Wikimedia Commons, licensed under CC BY 2.0.

Insects and arachnids have evolved to have different types of colour vision. Insects, for example, have trichromatic colour vision, which allows them to see three primary colours: ultraviolet, blue, and green. In contrast, arachnids, such as spiders and scorpions, generally have dichromatic colour vision, which allows them to see two primary colours: blue and green – although there are exceptions to this.

Insects usually have **compound eyes**, which are made up of many tiny lenses called **ommatidia**. Some insects can have over 20,000 ommatidia in each compound eye, which can give them an almost 360-degree range of vision. Each ommatidium contains a single photoreceptor, and the brain processes the signals from many ommatidia to create an image. Most insects can see ultraviolet light, which is used to detect nectar and pollen and is also used in mating behaviours. For example, bumblebees are trichromats, like humans, but the light wavelengths their photoreceptors detect are in a different range to ours – closer to ultraviolet light.

Most spiders have eight eyes, and each eye has a single photoreceptor. Some spiders can only detect light, but cannot see in colour. However, some species of jumping spiders have excellent colour vision, with four types of photoreceptors (tetrachromacy).

It is thought that some species of butterflies have the most photosensitive receptors of all insects.

> ***The bluebottle butterfly has 15 types of photoreceptor!*** *With one type of cone stimulated by ultraviolet, another by violet, three by varying shades of blue, one blue-green, four by green and five by red light, the common bluebottle butterfly has five times as many colour photoreceptors as we do.[...] Researchers believe the butterflies only use four of their photoreceptors for day-to-day colour vision, while the others[sic] 11 are used in specific environments, such as picking out objects hidden in vegetation.* viewed 12/01/2023">[5]

The exact anatomy and systems of colour vision in many different kinds of animals are still being studied. There is much that is not yet fully understood. We can study the anatomy of different eyes and how they detect light and colour, but we don't exactly know how each animal's brain interprets the information from photoreceptor cells like rods and cones.

The research to date has provided valuable insights into the evolution and function of colour vision in these animals. You can find out more about how different animals see colour by starting your own research online. You can visit the links on this page or search online or at the library to find books, journal articles and videos on this topic.

Media attribution: Watch: How Animals and People See the World Differently, National Geographic, on YouTube

**Further reading on colour vision in animals**

Color Matters – How animals see color

Wikipedia – Evolution of color vision

Ask A Biologist – Colors animals see

Cosmos Magazine – The incredible and bizarre spectrum of animal colour vision

Queensland Brain Institute – Colour vision in animals: a comprehensive overview

Natural History Museum UK, *How do other animals see the world?*

Natural History Museum UK, *Amazing eyes: 17 vision champions*

Gerl, E.J. and Morris, M.R. The Causes and Consequences of Color Vision. *Evo Edu Outreach* 1, 476–486 (2008). https://doi.org/10.1007/s12052-008-0088-x, accessed 12/01/2023

Kelber A. and Osorio D. 2010, From spectral information to animal colour vision: experiments and concepts, *Proceedings of the Royal Society B., Biological Sciences,* 277: pp.1617–1625 DOI:http://doi.org/10.1098/rspb.2009.2118, accessed 12/01/2023

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2. Scoggins, J. 2016, "Colour and Vision in Dolphins", *Sea Watch Foundation*, <https://www.seawatchfoundation.org.uk/colour-and-vision-in-dolphins/>, accessed 12/01/2023
3. Höglund J., Mitkus M., Olsson P., Lind O., et al (2019), 'Owls lack UV-sensitive cone opsin and red oil droplets, but see UV light at night: Retinal transcriptomes and ocular media transmittance', Vision Research, Vol 158, Pages 109-119, https://doi.org/10.1016/j.visres.2019.02.005. (https://www.sciencedirect.com/science/article/pii/S0042698919300471), accessed 12/01/2023
4. Bowmaker, James & Loew, Ellis & Ott, Matthias. (2005). The cone photoreceptors and visual pigments of chameleons. Journal of comparative physiology. A, Neuroethology, sensory, neural, and behavioral physiology. 191. 925-32. https://doi.org/10.1007/s00359-005-0014-4., accessed 12/01/2023
5. Smith, B. 2016 "The spectrum of animal colour vision", Cosmos Magazine, <https://cosmosmagazine.com/science/biology/the-incredible-and-bizarre-spectrum-of-animal-colour-vision/> viewed 12/01/2023

# Test yourself: the eye – how we see colour

## A multiple choice quiz to test your understanding of how the eye sees colour

**(5 minutes or less)**

**How did you go?**

If you need to learn more about this topic, you can read this section again: 2.3 The eye – how we see colour

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# 3: PART 3- APPLICATIONS WITH COLOR




## Chapter Overview: Understanding Colour in Theory and Practice

Colour is an essential part of visual communication. It affects how we see the world, how we respond emotionally to images, and how artists and designers create meaning. In this chapter, you will explore how colour functions across daily life, digital media, printed materials, pigments, dyes, and creative practice.

This chapter introduces the major systems artists and designers use to understand and apply colour. You will examine the difference between additive colour, used in digital screens, and subtractive colour, used in printing and physical materials. You will also learn how digital colour formats such as RGB, hexadecimal codes, HSL, and HSV help define colour in electronic media, while CMYK and spot colour systems help manage colour in print production.

In addition to technical systems, this chapter explores the history and material qualities of pigments and dyes. From prehistoric pigments to synthetic dyes and contemporary sustainability concerns, colour has always been connected to culture, technology, material access, and human creativity.

You will also study colour wheels, colour relationships, and common colour schemes such as monochromatic, analogous, complementary, split-complementary, and triadic palettes. These tools help artists and designers create harmony, contrast, emphasis, mood, and visual organization. Key colour terms such as hue, value, saturation, chroma, tint, shade, tone, and achromatic grays will support your ability to describe and analyze colour with greater accuracy.

By the end of this chapter, you will have a stronger understanding of how colour works in both theory and practice. You will be able to identify colour systems, explain how colours mix, compare digital and print applications, recognize important colour relationships, and apply colour vocabulary to your own creative work. This knowledge will help you make more intentional colour choices in studio art, design, digital media, and visual communication.


3.1: Introduction

3.2: Additive and Subtractive Colour

3.3: Colour Systems- Digital

3.4: Colour Systems- Printing

3.5: Colour Systems- Pigments and Dyes

3.6: Colour Wheels and Relationships

3.7: Color Terms

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# 3.1: Introduction

## Colour theory: working with colour

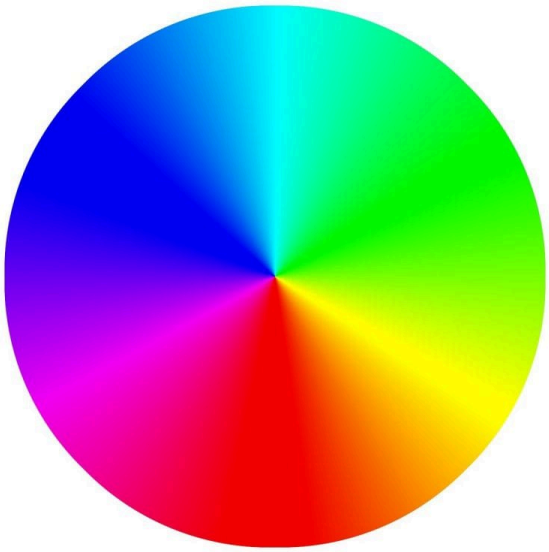


Figure 3.1. Colour wheel by TheDigitalArtist via Pixabay, licensed under CC0.

## Introduction

Colour is used in so many aspects of our lives – in the objects and environments that we see all around us every day, our clothes, homes, art and design creations, and digital media like photography, videos, games and websites.

This chapter explains the colour systems used in mixing and creating colour in both digital media, such as images, videos, websites, and physical materials, such as printing, paint pigments, and dyes.

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# 3.2: Additive and Subtractive Colour

## Additive and subtractive colour systems

### Additive Colour

Additive colour works by mixing colours of light. The more colours of light you **add** together, the closer you get to **white light**. It is the opposite of the colour spectrum, where white light is *refracted* (broken up) into a rainbow of colours.

Additive primary colours are **Red, Green and Blue (RGB)**. These are the colours from which all other colours of light are made. You can see evidence of this on your computers, televisions and mobile phones. Pixels emit light in different colours based on how much of each primary colour is emitted from each pixel (RGB values).

More about additive colour can be found in this resource: 3.3 Colour systems: digital.




Figure 3.3. Interactive Additive Colour Mixer. Image attribution: Interactive Additive Colour Mixer by Lisa Cianci, Creative Commons licence Attribution-Non-commercial-ShareAlike-4.0

### Subtractive Colour

Subtractive colour involves mixing physical materials like paint pigments, printing inks, and dyes. The more colour materials you mix, the darker the colour gets. It's called 'subtractive' because of the absorption or ***subtraction*** of certain wavelengths **from white light**. This absorption is based on how different atoms behave when light hits them. See PART 2- The Visible Spectrum" data-cke-saved-href="/Courses/Coalinga_College/Color_Theory_and_Applications/02:_PART_2-__The_Visible_Spectrum" href="/Courses/Coalinga_College/Color_Theory_and_Applications/02:_PART_2-__The_Visible_Spectrum" data-quail-id="29">Chapter 2. Colour theory: the visible spectrum in this resource for more information about the physics and chemistry of colour.

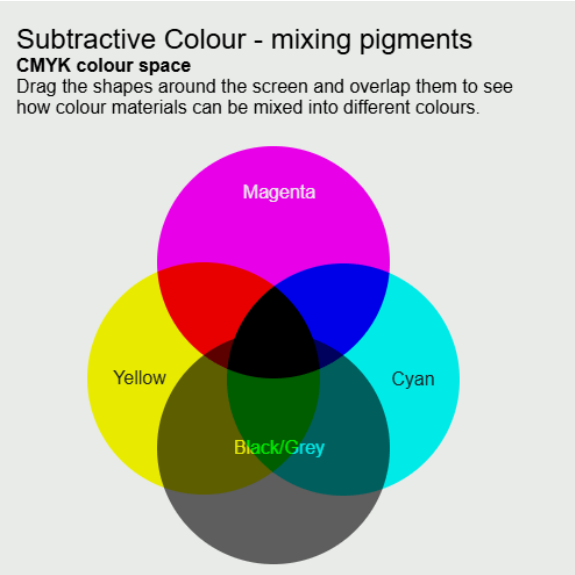



Figure 3.4. Interactive Subtractive Colour Mixer. Image attribution: Interactive Additive Colour Mixer by Lisa Cianci, Creative Commons licence Attribution-Non-commercial-ShareAlike-4.0

Subtractive primary colours are **Cyan, Magenta and Yellow (CMY)**. The traditional primaries **Red, Yellow and Blue (RYB)** are also useful to know about in some contexts, like understanding the historical development of colour theory and using older colour wheels. Psychological primaries **Red, Yellow, Green and Blue** are colours that were once also defined as primary because of historical colour theories about how our eyes perceive colour. See Biology of the human eye for more information about human colour vision and subtractive colour.

**A simple example to explain how subtractive colour works**

Observe something yellow, like a bowl of lemons with white light shining on it (Figure 3.5). The lemons are **reflecting** light wavelengths that we perceive as yellow and **absorbing** all other light wavelengths. We see a yellow colour because its opposite colour – blue (and other similar light wavelengths) is **subtracted** from the white light. Red and green light when mixed create yellow, so certain amounts of red and green light wavelengths (and other wavelengths between red and green) bounce off the lemons and our eyes see those light wavelengths as yellow.

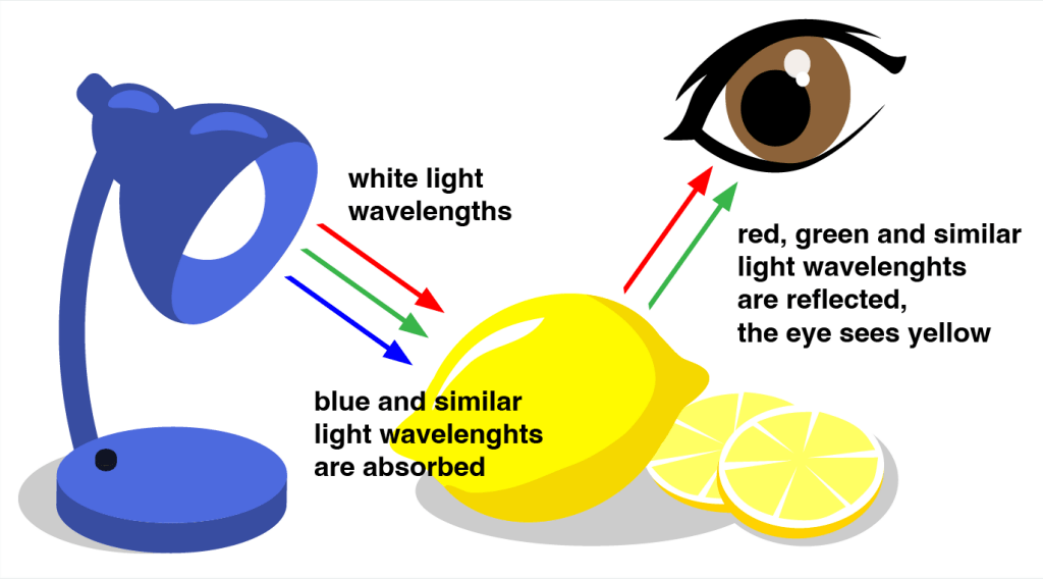


Figure 3.5. How subtractive colour works by RMIT, licensed under CC BY-NC 4.0 using images by OpenClipart-Vectors and Simona via Pixabay, CC0.

**Note: for printing, we use the CMYK colour system. In this system, K represents blacK. Black is used as an extra colour when printing because conventional CMY printer inks don't blend well enough to create a good black colour. Also, black ink tends to be much cheaper than coloured inks.**

More detailed information about subtractive colour can be found in 3.4 Colour systems: printing and 3.5 Colour systems: paint pigments and dyes.

## Additive and subtractive colours on the colour wheel

You might observe from the diagram on the previous page that mixing two additive primary colours gives you a subtractive primary colour. You might also observe that mixing two subtractive primary colours gives you an additive primary colour. This can be confusing until you understand how additive and subtractive colour works.

> *The confusion is at once resolved when it is realized that red, green, and blue are selected as additive primaries because they provide the greatest colour gamut in mixtures. For the same reason, the subtractive primaries are, respectively, red-absorbing (cyan), green-absorbing (magenta), and blue-absorbing (yellow).*[1]

Our current scientific knowledge and practical understanding of additive and subtractive colours have led to a more accurate colour wheel that displays both additive and subtractive colours, as shown in Figure 3.6.

Chapter 1. Colour theory: history and culture describes varied theories of primary, secondary and tertiary colours throughout history. This includes some very different examples of colour wheels, including the RYB (Red, Yellow, Blue) colour wheel (Figure 3.7), which is still used in some contexts to teach colour mixing in visual arts.

**Here is an image example of a contemporary colour wheel that shows additive primary, secondary and tertiary colours:**

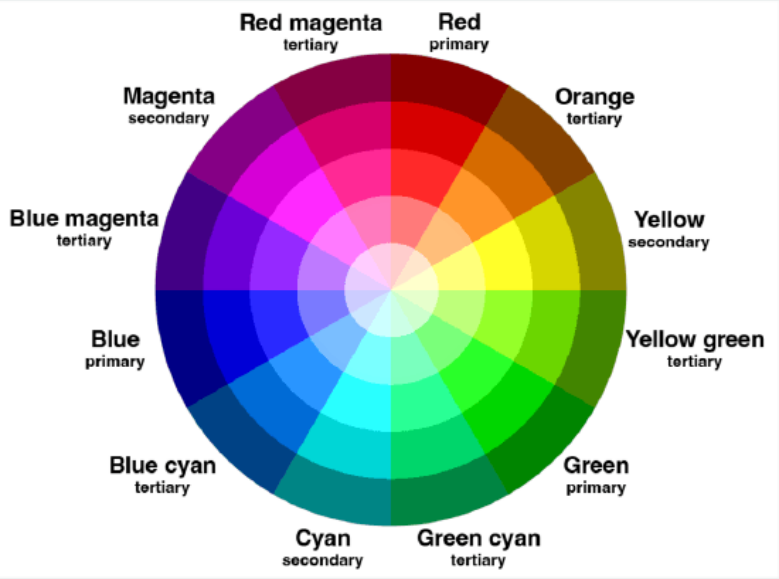


Figure 3.6. RGB colour wheel by RMIT, licensed under CC BY-NC 4.0.

**And here's an image of a traditional RYB colour wheel**

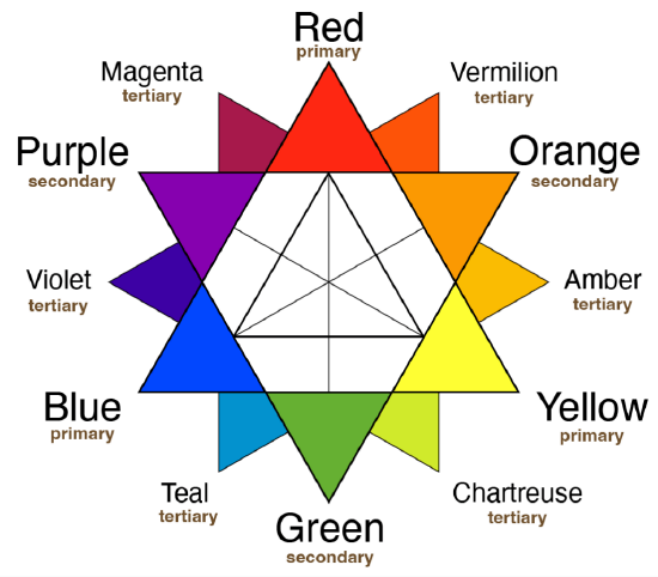



Figure 3.7. RYB color star (modified to show primary, secondary and tertiary colours), by Kwamikagami via Wikimedia Commons, licensed under CC BY-SA 4.0.

To see an interactive colour wheel with colour relationship options, visit 3.6 Interactive colour wheels and relationships in this resource.

1. Encyclopedia Britannica online (*Britannica.com*), 'The Visible Spectrum' https://www.britannica.com/science/color/The-visible-spectrum

## How additive and subtractive colour works when printing a digital image




Figure 3.8. RGB to CMYK conversion flow diagram by RMIT, licensed under CC BY-NC 4.0

When you create a digital image and then print it on paper, this involves a process of converting the additive colour system (RGB colour) in your digital image to a subtractive system (CMYK colour inks) that prints the correct colours onto paper.

Your image editing software or printer software is going through this conversion process, attempting to match what we can see on the digital screen with what will come out of the printer. It's a complex process, and there are many different automated and manual methods for colour conversion.

More detailed information about subtractive colour and the print process can be found in 3.4 Colour systems: printing. View this page for more about converting images from RGB to CMYK.

## Practical activities: mixing additive and subtractive colours

These practical activities can help you to understand how additive and subtractive colour works, and when we use each one to mix colours.

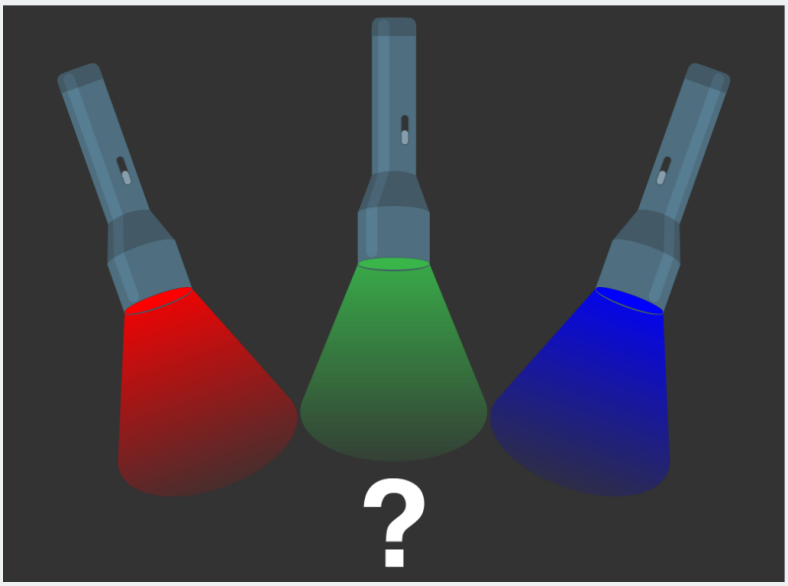
**Additive colour activity**

You can do some experiments at home with torches and red, green and blue coloured cellophane or transparent coloured plastic or glass to test how additive colour works (you can also do this experiment with red, green and blue LED lights).

If you have red, green and blue cellophane, you can cover three torches – each with different coloured cellophane.

In a darkened room, shine the coloured light from the three torches on a white piece of paper or a white wall so the coloured light overlaps.

What do you see? How many colour combinations can you make?




Interactive Content

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this Interactive Content online

What happens if you layer two colours of cellophane together – red and green on the one torch, for example?

Does any light shine through the two layers onto the paper? How can you explain this with what you know about additive and subtractive colour? (Hint: the light waves are filtered through one layer of cellophane first, then the other.)

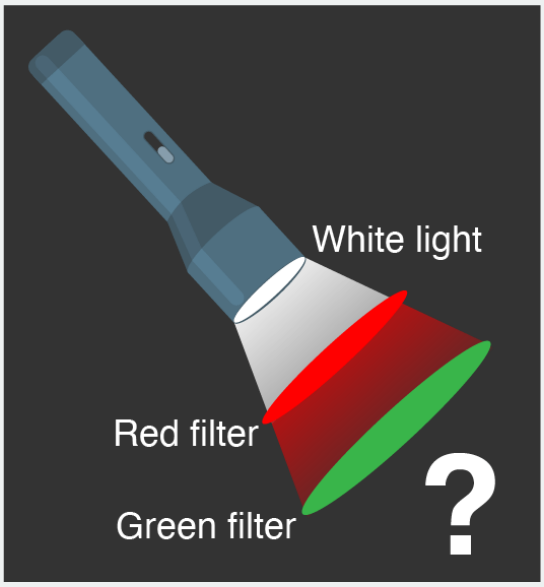



Figure 3.10. Additive colour – two filters on one torch by RMIT, licensed under CC BY-NC 4.0.

Interactive Content

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this Interactive Content online

**Subtractive colour activity**

Mix paints, inks or felt-tipped pens of different colours to see how many different colours you can make on white paper. It's easy to make darker colours with these materials, but how hard is it to make a lighter colour without using white paint or adding water to thin the colour out?

Most cheap sets of felt-tipped pens have cyan, magenta and yellow colours, as well as red, green, blue, black, brown and possibly even grey. What colours can't be mixed from other colours? There's more information on mixing subtractive colours in 3.4 Colour systems: pigments and dyes in this resource.



Figure 3.11 Coloured pencils. Image by Stefan Schweihofer via Wikimedia Commons, licensed under CC0.

**Additive to Subtractive colour activity**

If you have a digital editing or drawing software app on a computer, tablet or mobile phone, try and find the colour wheel, colour picker or colour sliders to select different colours to draw or paint with.

See if your app has information about RGB colour, CMYK colour, or other colour systems like *Hexadecimal* (covered in the next part of this resource – 3.2 Colour systems: digital). If you can print an image from your digital device, compare the colours on the screen to your printed image – how similar are they?

Often the RGB-Red to CMYK-Magenta/Yellow-mix colour conversion is the hardest to get right when printing digital images, although greens and blues can be tricky too, depending on the quality of your printer and printing inks.

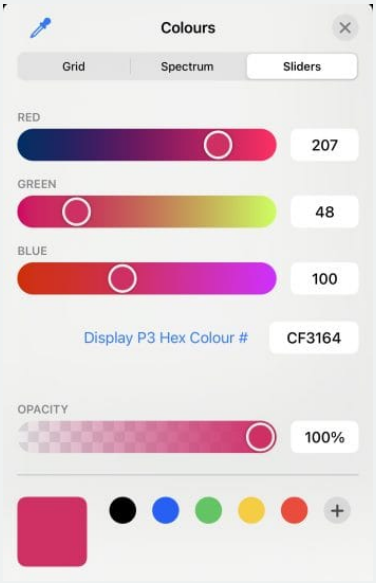



Figure 3.12. Colour slider example. Image attribution: Colour slider image from GIMP image manipulation software application, GNU public licence v.3

# Test yourself: is it additive colour or subtractive colour?

## A multiple choice quiz to test your understanding of colour systems

**(5 minutes or less)**

View each type of colour application and choose if it's using **additive** or **subtractive** colour systems, or **both...**

**How did you go?**

If you need to learn more about this topic, you can read this section again.

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# 3.3: Colour Systems- Digital

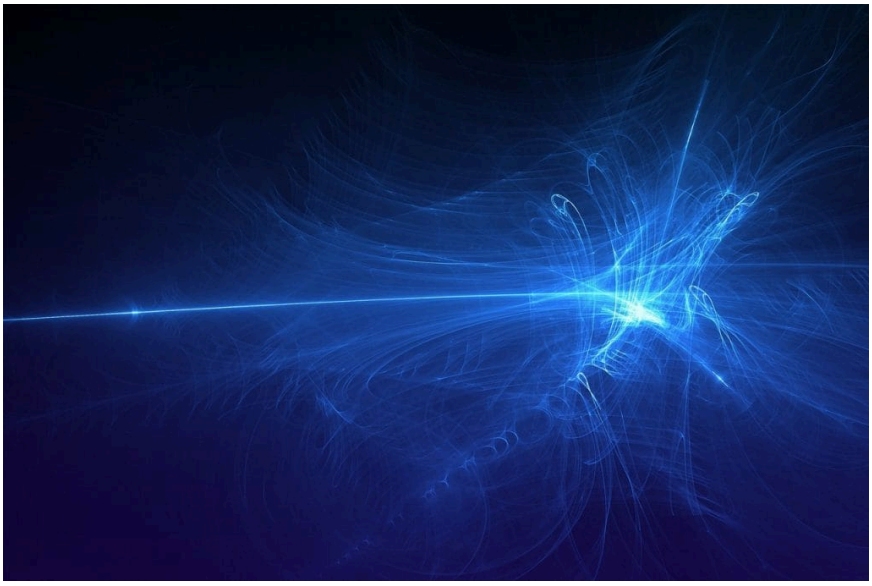


Figure 3.19. Digital abstract image by RaniRamli via Pixabay, licensed under CC0.

## Colour gamuts and colour spaces

The previous section of this resource explained the **Additive RGB** colour system, which is the system used for colour in digital media. However, there are multiple colour spaces related to RGB that are used to describe and create the millions of colours that our digital screens can display – and that we can see with human eyes. It's useful to know about this if you are working with digital tools and software applications to create digital media.

### Colour Gamut

**Colour gamut** (also known as **colour space**) is the complete range or subset of colour that can be produced or recorded by an application, system or device.

A common representation of the colour gamut used in digital and print systems is shown in Figure 3.20, which displays the **gamut** of **visible colours** and the extent of different colour spaces within that.

You can see that the RGB colour space and the CMYK colour space are smaller than the LAB colour space – which is what the human eye can see (for more about CIELAB colour space, visit Contemporary Colour Systems (c. 1930 – 2020+) in this resource).

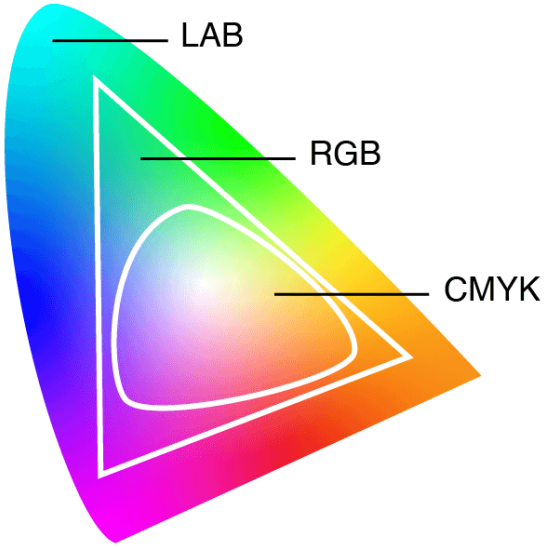



Figure 3.20. CIELAB, RGB and CMYK colour spaces – approximate values only, by RMIT, licensed under CC BY-NC 4.0.

Learn more about colour gamut and colour space :

- Wikipedia: Gamut
- Wikipedia: CIELAB_color_space

## RGB colour spaces

There are multiple RGB colour spaces, and they each have different colour gamuts. Some have more greens or more reds and yellows. Some are better for digital-to-print conversion. Here is a summary of some popular ones you will probably find on your digital devices:

**sRGB** is a standard RGB colour space (or colour gamut) that HP and Microsoft created cooperatively in 1996 to use on computer displays, printers, and the Internet. It was standardised by the International Electrotechnical Commission as IEC 61966-2-1:1999.

It is a preferred standard for web-based media, and many websites and video games have been made using this colour space.

**opRGB** or **Adobe RGB** was developed in 1998. It was designed to represent most of the colours achievable on CMYK printers, but by using RGB primary colours on a computer display or digital device.

The Adobe RGB colour space encompasses approximately 50% of the visible colours specified by the CIELAB colour space, which improves on the sRGB colour gamut, mainly in cyan-green hues. It was standardised by the IEC as IEC 61966-2-5:1999 with the name opRGB (optional RGB colour space) and is used in HDMI (High Definition Multimedia Interface) – a standard for simultaneously transmitting digital video and audio from a source, such as a computer or TV cable box, to a computer monitor, TV or projector.

**DCI p3** (Digital Cinema Initiatives – Protocol 3) is a more recent standard used by the film industry – mainly for films shown in cinemas. It covers around 45% of the visible colours of the CIELAB colour space and has a wider range of colours than sRGB – around 25% more colours. This increase in visible colour allows for more vibrant colours and can also be used by screens that can display 30-bit colour, such as HDR TV screens. It favours an increase in red-yellow colours as opposed to Adobe RBG, which favours blue-green colours.

Viewsonic: using DCI p3 color gamut for video editing

In a practical application, these different colour spaces can affect how we see images, movies, video games etc., on different devices and why sometimes graphics can look better or worse on different screens. See the next page for details about how digital screens work.

## How digital screens display colour

Pixels on our digital screens emit light in different colours based on how much of each primary colour is emitted from each pixel (RGB values). The number of colours we can see created from a digital RGB system depends on the 'colour depth' of our screens (also called *monitors* or *displays*).

The first colour computer screens had an '8-bit' depth which only displayed 256 colours (you might remember old 8-bit video games with very basic colour graphics). Now we have ***true colour*** on most computers, which is 8-bit for each RGB colour – or '24-bit' depth. This can display over 16.7 million colours.

Some recent high-quality computer displays have '30-bit' depth, which can display 1.07 billion different colour combinations. There is debate about the need for so many colours and whether our eyes can see the difference, although it is claimed that having over one billion colours is useful in certain situations when working with very bright, very dark or very light colours, where a finer level of definition is needed.

Viewsonic: color-management and color blindness – how can monitor technologies help?

### Colour calibration

Calibration is the process of aligning your digital screen's colour output to the RGB standard – so what you are seeing on your screen is a true representation of the RGB colours created by your computer. This process is important for working with digital content like photography and digital-to-print processes where it's necessary to have colour accuracy. Most computer systems will have their own calibration tools, or you can find online applications to help you calibrate your screen.

**Activity – test and calibrate the colours on your digital devices**



Figure 3.21. Test Pattern. Image by Zacabeb via Wikimedia Commons, licensed under CC0.

Save a link to this page and open it on all of your digital devices. View the test pattern image in Figure 3.21 and see how it looks on your computer, tablet, mobile device and TV screen. Are the colours different on each device? Is the brightness different? Can you adjust your settings to get the best colour and brightness on each device?

Learn more about digital screen calibration from these links:

- Calibrating – Les Walkling & Co (A great resource for digital media and printing from a significant Australian artist)
- Viewsonic: Color management – a checklist for digital artists
- Viewsonic: Best monitor calibration tool – hardware vs software – calibration
- Viewsonic: What is fogra and why does it matter?

## Television settings

Your home television has picture settings that change the colour, brightness and contrast according to perceived usage. The 'standard' picture mode might be OK for sports and reality TV but may not be the best for watching movies or drama series as they were intended by directors because it alters the colour settings. You may be able to change your TV settings to '**cinema'** or '**movie' picture mode** when watching movies or streaming TV series to get the best colour. See Colour grading in the Colour aesthetics section of this resource for more about the importance of colour in film and video.

Learn more about TV colour setting and "The Soap Opera Effect", TV picture settings for colour and motion smoothing.

# What is Hexadecimal colour?

## What is Hexadecimal colour?

The **Hexadecimal**, or **HEX** colour system, was developed for creating colours in **HTML (HyperText Markup Language)** for websites. It's another way of describing RGB colour values – with a single number.

Hexadecimal is a *base-16* number system (hex means 6, and decimal means 10), which allows us to represent larger numbers with fewer digits.

It uses the numbers 0 to 9 and the letters A to F to describe RGB value colours:

> **0 1 2 3 4 5 6 7 8 9 A B C D E F**

> **This is an example of a HEX colour**
> **(the hash symbol '#' denotes a HEX colour in HTML code):**
>
> **#E86F1F**
>
> - **E8** is the **Red** value
> - **6F** is the **Green** value
> - **1F** is the **Blue** value
>
> **Here's a swatch of the colour:**
>
> 

Note that the highest value is Red (E8 is a high number), the second highest is Green, and the last is Blue – which produces this particular shade of orange.

The same colour in RGB would have the following values:

**#E86F1F = RGB(232, 111, 31)**

The HEX value is a more efficient way of representing RGB colour information.

**This colour picker tool (Figure 3.22) shows RGB and HSV values, and the Hexadecimal colour value (HTML notation).**




Figure 3.22. Colour Picker showing various RGB colour values. Image attribution: Colour picker image from GIMP image manipulation software application, GNU public licence v.3

White in HEX colour is **#FFFFFF** – the highest number – and black is **#000000** – the lowest number.

If you convert **#FFFFFF** from a hexadecimal to a decimal number, you get the number **16,777,215** – which is the exact number of colours that can be displayed on 24-bit computer displays.

If you want to test your HEX colour identification skills, you can try this online guessing game – WHAT THE HEX? – It's fun and can be addictive!

## Other RGB colour models

Within RGB colour space, there are different models for describing aspects of colours. These were originally developed for different purposes like television or computer graphics. Representations of these models are still found in many common image editing applications.

**HSL** represents the values of **Hue**, **Saturation**, and **Lightness.**

**HSV** represents **Hue, Saturation**, and **Value (**also referred to as **Brightness)**

**HWB** represents the values of **Hue**, **Whiteness**, and **Blackness.**

- **Hue** is the colour wavelength on the visible spectrum
- **Saturation** is the intensity of that colour, and;
- **Lightness** describes lighter and darker variants of a colour.
- **Alpha-channel**: in **HSL-A** colour or **RGBa** colour, the **A** represents the **Alpha channel**, or *transparency* of the colour, which is used in image editing and web design contexts to allow for transparent layers of colour to be represented.
- **Value/Brightness**: this value is different to Lightness in HSL – it relates to how bright a colour is, not how light (pale) or dark a colour is.
- **Whiteness & Blackness** – used in the **HWB** colour model, these values are different to Lightness and Brightness and

represent how much white or black is mixed with the Hue.

It can be confusing to understand what these different values mean until you see them working in a practical way. Here is an interactive colour selector you can use to learn about different colour values. You can enter a colour value and it will display values for six different colour models

**Activity: type an RGB, HEX, or other set of colour values into the space provided and see the colour and values for each model.**

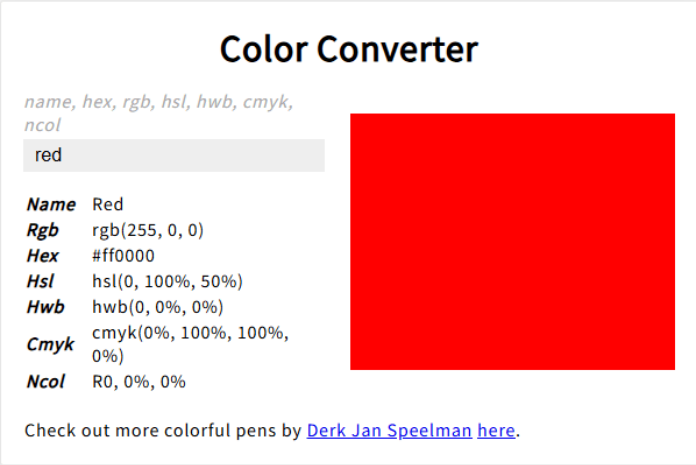



Figure 3.23. Colour converter tool. Media attribution: Interactive colour converter (JavaScript) by Derk Jan Speelman on CodePen

## How do digital images and videos display colour?

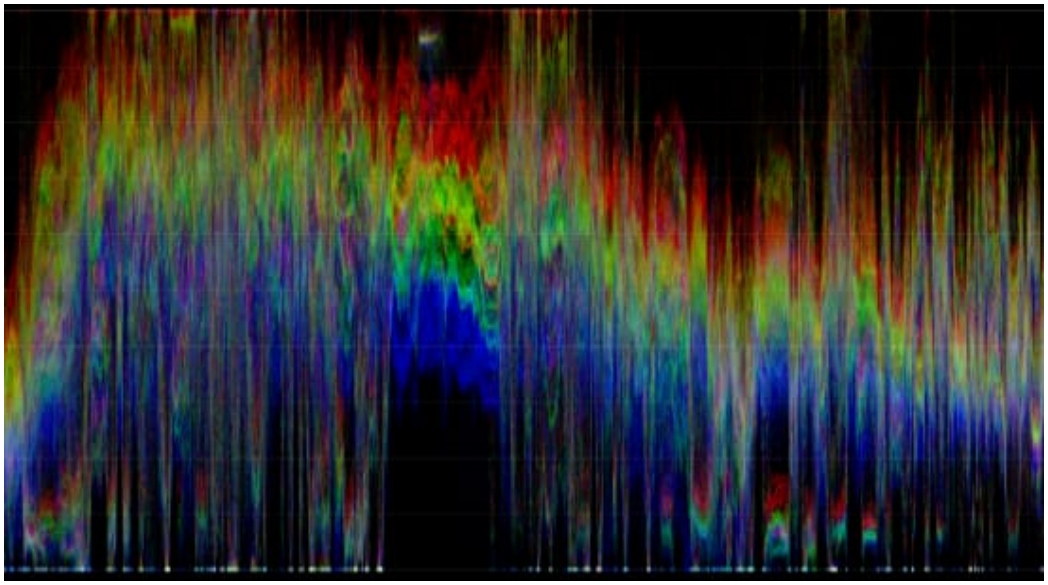


Figure 3.24. Waveform (RGB) data from MP4 video. Image attribution: Waveform RGB data from MP4 video by Lisa Cianci, Creative Commons licence Attribution-Non-commercial-ShareAlike-4.0

Digital image and video objects record and store colour information in different ways depending on their format and encoding methods. When creating visual digital media content, we usually want to have the best quality image possible, but with the smallest file size possible to allow for fast internet download and rendering by software applications.

**Topics covered on this page**


- Resolution
- Compression and encoding
- Image file formats
- Digital video properties
- Video codecs


## Resolution

Both image and video files have properties such as **Resolution**, **Width**, **Height**, and **File size**.

**Resolution** is how much detail the image holds. This is measured by pixel count in digital images and video. Pixels are tiny squares or dots of colour that form the rectangular grid of an image or video's visible area. The more pixels in your image, the higher the resolution and the more detail or information stored in the image. This also means better quality and colour.

You might notice on your digital camera or mobile phone how many **megapixels** the camera can capture. This is the total number of pixels (one megapixel equals 1,048,576 pixels, usually rounded down to 1,000,000 pixels) that can be recorded in a single image. Higher megapixels give a higher-quality image. If your camera can capture an image that's 12 megapixels, this would be an image that is approximately 4290 x 2800 pixels in width and height.

**Image resolution is important to understand if you're working with screen and print media.** We generally use a lower resolution image for screen media and content on the Internet because we want fast loading times, and our screens have a limited resolution display. For printing, a higher resolution is better for image quality. Printers can print at different resolutions depending on their capability. Commercial and professional printers can produce extremely high-resolution imagery necessary for fine art photography and publications. Your home inkjet printer can also print at different resolutions, depending on the quality of the printer.

Resolution in images is measured by the number of pixels in width multiplied by height, but also the **density** of those pixels – measured by **dots per inch (DPI)**, which is how many dots/pixels are in a square inch. The higher the DPI, the better quality the image will be.

**The image in Figure 3.25 on the left is low-resolution. It only has 1% of the information contained in the high-resolution image on the right. Select the image to enlarge.**



Figure 3.25. Example of low and high resolution versions of the same image, from a photo by lum-box via Pixabay, licensed under CC0.

Have you ever seen an image on a webpage that looked great on your computer, but when you try to print it, it looks terrible? This is because the screen image has a low resolution – possibly 72 DPI – and low dimensions – possibly 800 pixels width x 600 pixels height or less.

Your printer can produce images that are anywhere from 150 to 1200 DPI (or higher, depending on the printer), so your small image doesn't have enough pixels to produce a good quality print image.

**It's important to save your image at the right resolution and dimensions for its purpose, and to use the right colour system – RGB for screens, CMYK for print.**

**Also important!!** Once you have reduced an image's resolution – width/height or DPI – and saved it, that information is lost. If you try to increase the resolution, your editing software compensates by duplicating or replacing pixels and filling in the space according to its encoding system, but it cannot replace that lost information, so you'll still see a blocky and pixelated image. This affects the colour as well – the lost colour information cannot be replaced.

Many software editing applications have processes that attempt to compensate for the loss of information, and more recently Artificial Intelligence (AI) is increasingly used to 'intelligently' enhance image quality by replacing the lost information or repairing images that are damaged or blurry. These tools are useful, although if you work with very high-resolution images, image enhancement is no match for retaining the original image information.

Learn more about AI image enhancement from this article about AI super resolution.

## Compression and encoding

More pixels results in a bigger file size – which is the number of bytes (kilobytes, megabytes, gigabytes, terabytes, etc.) in the file. This can be problematic with video – even a short video can have thousands of frames and in theory, each frame is an image. Video files are much bigger in file size than still images.

Image and video files also store colour information in different ways.

## Image file formats

**RAW** is a ***raster*** image format (based on a fixed grid of pixels) used for unprocessed images usually captured with a camera. There are many different RAW image formats, and these are often dependent on which camera you use. RAW images are ultimately converted to another format to be used for digital media (JPEG, PNG) or print (TIFF, high-quality JPEG). Your camera or mobile device may have the settings option to save images as RAW or JPEG.

*Note: RAW images will take up more file space on your device.*

Think of a RAW image like a traditional physical photographic negative that can be reproduced in multiple formats (although a RAW image is not a negative image). Keeping a RAW version of an image means that you have all the original information of the image, which can then be altered using ***non-destructive editing techniques*** to achieve a particular result. For example, you might change the exposure, brightness, contrast, and colour values of an image in your editing software and save that as a TIFF image file for printing, but you still have the original RAW file to return to if you want to create a different version of the image with different colour values.

Learn more about RAW
Learn more about non-destructive editing.

**GIF** (Graphics Interchange Format) was one of the first raster image formats used on the Internet. It has a very limited palette of colours available – only 256 colours. This is partly because it was created when bandwidth was much lower and slower than it is today. Only the smallest of image file sizes could be used to share images across networks or display graphics on web pages. Also, screens only displayed 256 colours at that time, so there was no requirement for more colour information. The innovative compression used in GIF identifies repeating patterns, then simplifies them, allowing for lossless compression of files – meaning none of the data is trimmed in the shortening process (Lempel-Ziv-Welch compression algorithm).

GIF images can save different minimal colour 'palettes' – you can choose to save only the colours used in the image (indexed colour), which makes the file sizes very small. Because of the limitations of GIF image colour, it is a good format for simple graphics like logos but not good for photographic images. You can also save transparency in a GIF image – which is useful for something like logo design, where you might want a transparent background so that the same image can sit on different coloured backgrounds – for example, in webpages.

GIF was the first common image format that allowed animation (WebP images also allow animation, but are not commonly used at this time). Animated GIFs are multi-frame images that hold information like frame rate and looping properties. They have had a resurgence in popularity on social media and in meme culture because they are usually very short in timeframe and small in file size, therefore easy to access on mobile devices.

Learn more about GIF:

Smithsonian magazine: A Brief History of the GIF, From Early Internet Innovation to Ubiquitous Relic.

The **JPEG** (Joint Photographic Experts Group) raster image format became a standard image format in the late 1980s and early 1990s. It allows for millions of colours in an image (24-bit colour), which is good for capturing photographic images. JPEG uses a system of **lossy compression** to reduce the amount of information in an image file and therefore reduce the image file size – making it a useful image format for the Internet.

It's called 'lossy compression' because visual data that the human eye can't see is removed, and colour variation is averaged, so some of the image information is lost in the compression process. You might have seen low quality JPEG images on websites or social media where the image looks blocky or has visible 'artefacts' (noise or aliasing on the edges) – this is due to the JPEG format compression.

The user can control the level of compression in a JPEG image – more compression results in a lower quality and smaller file size. Less compression results in a higher quality and bigger file size. Your image editing software will give you compression options when you save your image as a JPEG/JPG file.

Learn more about JPG:

JPEG.org: jpeg.

Adobe: jpeg.

**SVG** (Scalable Vector Graphic) is a very different kind of image format. It is not a resolution-dependent raster image format, rather, it is based on ***vector graphics***, which are mathematical statements that describe lines, curves, shapes and colours on the Cartesian plane (x,y axis). This makes it ***scalable***, so no matter how big or small you size the image, it will retain its quality – it redraws the geometric information at any size. Because an SVG file stores mathematical information and not pixel information, SVG files are generally very small and can also be used in websites as XML code.

This kind of graphic is generally not used for photographic images – calculating the vector maths for a complex photographic image would be less efficient than using pixels and compression formats. However, vector graphics are very useful for visual materials that need to be reproduced at different sizes in both digital and print media, such as advertising graphics output like posters, banners, billboards, signage, etc. Other common vector image file formats that digital media creators may encounter include EPS, AI, and PS.

Learn more about SVG.

There are many, many more image file formats that are useful to know about when creating digital media, such as:

- **PNG** – (Portable Network Graphic): raster image format good for photographic images, supports lossless compression and has millions of colours, transparency (PNG-24), and is commonly used in webpage design.
- **TIFF** – (Tag Image File Format): raster image format popular with photographers for storing lossless, high-quality images for printing.
- **BMP** – (Bitmap): a high-quality, uncompressed raster image format. Originally created by Microsoft.
- **HEIC** – (High Efficiency Image Format): a more recent raster file format that has better quality than JPEG, using HEVC (High Efficiency Video Coding) for compression. It is now commonly used in Apple devices. A HEIC image may be half the size of a JPEG but with higher quality.
  Adobe: HEIC vs JPEG.
- **WebP** is a more recent raster image format developed for the web. It has better quality lossless and lossy compression compared to either PNG or JPEG. It uses predictive coding to compress the visual data, resulting in comparatively small file sizes, and is currently supported in recent browsers. You can also have animated WebP images.
  Google developers: WebP.

There are also ***native*** image file formats that are the image files created by particular software applications. For example, Adobe Photoshop has a native file format that has the extension **PSD**. This file can only be used by Photoshop – you have to export a JPEG, PNG, GIF or another type of file from the Photoshop PSD file if you want to use your image on the Internet for example.

Learn more about image file formats from this video (14 minutes):

Media attribution: Explaining Image file Formats, Explaining Computers on YouTube

# Digital video properties

Video files without compression are so big in file size that they would be very slow to download – even with very fast Internet – and difficult to play without ***lagging*** and ***buffering*****.**

If we didn't have compression, you wouldn't be able to stream videos from platforms like Netflix or Google Play.

A video file has certain properties:

**Container** – type of file – MP4, AVI, MOV, etc.

**Dimensions/resolution** – width and height in pixels (Figure 3.26).
Some common video resolutions:

- SD (standard definition) any video with a height of 480 pixels or less
- HD (high definition) – 1280 x 720 pixels
- full HD – 1920 x 1080 pixels
- 4K UHD (Ultra HD) – 3840 x 2160 pixels
- 8K (full ultra HD) – 7680 x 4320 pixels

**This image shows the difference in video resolutions – select the image to enlarge**




Figure 3.26. Video resolution comparison by RMIT, CC BY-NC 4.0. from a photo by Babelphotography via Pixabay, licensed under CC0.

Learn more about video resolution here... Typito: video resolutions

**Frame rate** – how many frames per second (fps): 24 fps has been a standard frame rate for many years, 30 fps is used for TV broadcasts, 60 fps is becoming more common in 4K HD video, and for capturing slow motion footage, we see frame rates of 120 fps and higher, captured by high-speed cameras that can handle such high frame rates.

**Duration:** the length of a video in hours, minutes, and seconds (HH:MM:SS). For example, **01:30:24** describes a video duration that is one hour, 30 minutes and 24 seconds long.

**Bit rate (bitrate)** is the amount of data stored per each second in a media file (video and audio). It's measured in megabytes per second (MBPS).

- A **high bitrate** is associated with a **high resolution** and/or **low compression**, which means bigger file sizes.
- A **low bitrate** is associated with a **low resolution** and/or **high compression**, which means smaller file sizes.

As with still images, you can't turn a low-quality video into a high-quality video because there isn't enough data about the pixel colours in each frame to increase the resolution or replace the data lost in compression. AI tools may be able to fill in and define low-resolution video to improve quality. For example, grainy, low-light video footage can be smoothed and better defined, but this functionality is limited and is not equal to capturing high-resolution video in the first place.

Learn more about bit rate.

## Video Codecs

**Codec** (a *portmanteau* word for **coder-decoder**) is the software encoding method that compresses video data and stores it in the container (file) so it can be decompressed and played back.

Video compression, as with image files, reduces the amount of colour information stored in the video file without visually altering what the viewer can see. Most video codecs are **lossy** – some of the data of an uncompressed video file is lost in the compression process, necessary to make file sizes small enough to play back smoothly and download quickly or stream at the right speed.

There are many different kinds of video and audio codecs, and they all use different compression methods to reduce file size. Codecs in video work by reducing the data by **motion compensation**, **macroblocks** (large blocks of pixels that have the same colour or motion) and **chroma subsampling**.

Motion compensation uses keyframes – I-frames, P-frames and B-frames. I-frames contain the complete image, whereas P-frames look for which pixels have changed and only record the information for those changed pixels. I-, P- and B- frames make up what we call "groups of frames", and this method can reduce the size of the video file by up to 90%.

Chroma subsampling reduces the amount of colour information by using a different colour space instead of RGB. It's a complex system to understand: the **YCbCr** colour space works for video because the human eye is more sensitive to changes in brightness than changes in colour. **YCbCr** represents the following colour information in video:

- Y (luminance or luma)
- Cb (blue-difference chroma)
- Cr (red-difference chroma)

*luma = brightness, chroma = colour*

Some common video formats and their codecs:

> **MP4 (MPEG 4)** – the MP4 container is the current industry standard for HD video. It most commonly uses the **H.264 codec** (also known as Advanced Video Codec or MPEG Part 10), which supports up to 8K video. It produces high-quality video at a low bitrate which means smaller file sizes – useful for streaming video content online.
> Wikipedia: Advanced Video Coding.

> **MOV (Quicktime video format)** is an Apple standard video format that usually uses **MPEG-4 compression**. In fact, the MPEG-4 format evolved from the Quicktime file format (QTFF) around 2001. MP4 is a revised version of this.

> **AVI (Audio Video Interleave)** is a Windows standard video format created by Microsoft in 1992, which commonly uses the **DivX codec.**

Learn more about video formats, containers and codecs from this video (14 minutes):

Media attribution: Explaining Digital Video: Formats, Codecs & Containers, Explaining Computers on YouTube

Learn more about video here:

- Basics of video encoding
- Wikipedia: comparison_of_video_container_formats
- Wikipedia: comparison_of_video_codecs

# Test yourself: colour systems – digital

## A multiple choice quiz to test your understanding of digital colour systems

### (5 minutes or less)

### How did you go?

If you need to learn more about this topic, you can read this section again.

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# 3.4: Colour Systems- Printing

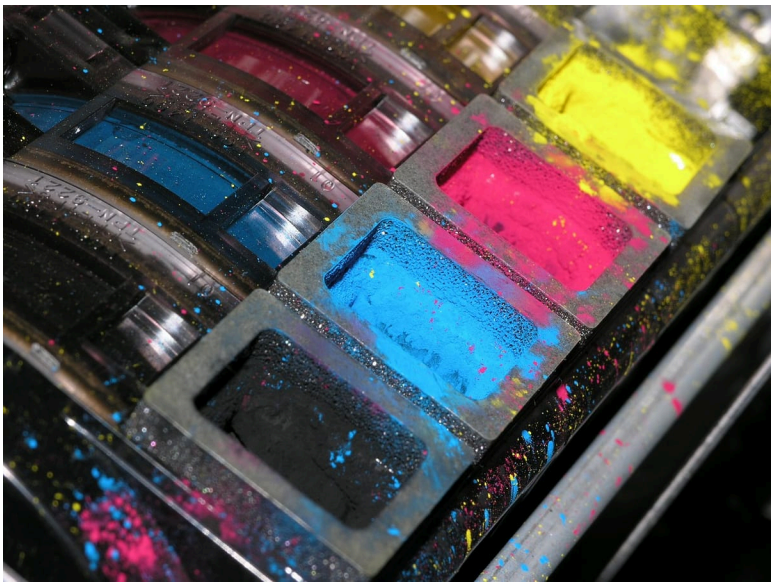


Figure 3.27 Printing machine with CMYK colour. Image by Magnascan via Pixabay, licensed under CC0.

Colour printing requires a range of different methods for printing all kinds of imagery onto different kinds of materials. This includes photographic imagery, artwork, publications, and graphic, industrial, fashion, and textile design products.

Understanding how subtractive colour systems work, how inks, pigments and materials behave in printing processes, and how to achieve effects like metallic and fluorescent colours or gloss and embossed finishes requires special skill and expertise.

This section is a short introduction to how colour works in printing – from digital media to a physical product.

## Do I need to convert an RGB image to CMYK to print it?

## Do I need to convert an RGB image to CMYK to print it?

You can send an RGB image directly to your home inkjet printer and it will print it out. However, this is relying on the printer's software to convert your RGB image into CMYK for the four or more inks that your printer uses. You may not get the best result by doing this, and your printed images may not have the most accurate colour.

***Note**: some inkjet printers also have a grey ink cartridge – CMYKg (and some also have green and orange) – the grey ink is a dye, whereas the black ink is a pigment and not transparent. Grey ink is good for shades and mixing with the other colou*

If you convert your RGB image to CMYK in your image editing software, you have more options and control over how the image will look when printed, and most professional printers will ask for images already converted to CMY

Watch this video to see some examples of RGB to CMYK colour conversion in action. You don't need to have Photoshop to convert your images, but it helps to have an image editor that has properties you can adjust to get the best results

Media attribution: Essential Tips Converting RGB To CMYK | The Art Of Printing | Getting Started | Matt Irwin, Matt Erwin Photography on YouTube

For a more technical and detailed overview of digital-to-print, see the **resources on this page by artist and authority on digital printing – Les Walkling**. In particular, see the PDF on ***Matching Prints to Screen.***

This video by Les Walking for the Colour Society is a more technical and detailed examination of the factors that affect the

conversion of digital image to print: link to video on Youtube (cannot be embedded):
**From Screen to Print: Mastering Colour Fidelity in Digital Media**

## Process (CMYK) and Spot (Pantone) colour printing



Figure 3.28. Printing house by andreas160578 via Pixabay, licensed under CC0.

Colour printing can be complex and requires specific skills and knowledge to perfect. Print methods used depend on the type of print job and the colours you want to print.

Not all colours can be produced with **Process** colour (also called the **four-colour process** because of the four inks used – **CMYK**). Process colour printing mixes colours by laying down tiny dots in the printing process. Process colour is good for photographic images and complex images with subtle tones and shades, but it's not good for some kinds of printing, like logos, packaging, or printing designs on fabric, like t-shirts.

**Spot** colour is what we call it when pre-mixed colours are used in the **offset** printing method (Figure 3.28). This method is preferred when a small set of exact colours are needed – or if colours are needed that can't be mixed with the process method – such as pastels, fluorescents, or metallic colours. Spot colours are solid colours and are usually made with the **Pantone** colour-matching system. There are 18 basic inks that are used to mix all the Pantone colour

Some printing jobs use both Process and Spot methods to achieve the best result. For example, some company logos require a very specific spot colour which can't be reproduced with process printing, so a spot colour is added to the Process colour printing to get the exact colour.

There is also a third printing method called **Extended Colour Gamut process colours.** This method is recent and not yet as popular. It involves adding additional colours (orange, green and violet – **OGV**) to the CMYK colour printing method to extend the number of colours (the gamut) that can be printed – **CMYK+OGV**.

Designers often refer to Pantone colour swatch books (Figure 3.29) and online swatch charts to help select and match colours for printing. You will also find colour libraries, including Pantone, in your image editing softwar

Visit these links for more information:

- Pantone: Spot vs process color
- Adobe: Spot vs process color
- Graphics Mob: How to find and add Pantone colors in Photoshop



Figure 3.29. Pantone swatches. Photo by Christina Rumpf via Unsplash, licensed under CC0.

## Colour management – what can go wrong?



Figure 3.30. Image attribution: Image by Gino Crescoli from Pixabay

**Colour management** is important to ensure colour is accurately represented across digital devices, screens and printing processes. It's useful to know about if you are a graphic designer, photographer, printer, or any kind of colour worker.

This chapter has covered working with colour from a range of perspectives, like colour gamuts and systems, different kinds of digital media devices, and printing methods. All of these elements are affected by colour management. Sometimes, things can go wrong in colour processes – especially when transferring images between devices or outputting to printers.

**What can you do to improve your colour management?**

If you know what can go wrong, you will know what to look out for and how to solve any problems that might happen. Here are a few things that you can check in your own colour workflow processes that might be creating colour problems for you:

1. **Screen colour problems (Calibration)**
   If you are working with an old computer screen/monitor, or one that isn't calibrated properly, you may not be able to see the correct colours in your digital media. Try calibrating your device screen to get the colours as accurate as possible. See How digital screens display colour in this resource for more information.
2. **RGB to CMYK (Conversion)**
   Not converting RGB images to CMYK before printing, as mentioned in Do I need to convert an RGB image to CMYK to print it? in this resource.
3. **Image editing in CMYK instead of RGB**
   This will not show you accurate colours on your computer, and may not let you use all the editing functions of your software. Check that you are editing your image in RGB to get the best results.
4. **Colour loss from conversion**
   Understanding the different colour systems and colour loss when converting from RGB and CMYK is useful. RGB is a bigger colour gamut than CMYK, so not all colours transfer from digital to print.
5. **Do you have the right colour profile?**
   If you're not using the right colour profile or library when creating/editing your digital images, your colour may not print accurately. Learn about colour profiles here: Adobe: working with colour profiles
6. **Colour correcting**
   Learn how to use colour pickers and HSB settings to change the saturation or brightness of colours and adjust your images where necessary. See Other RGB colour models in this resource for more information.
7. **Double colour management**
   If your software and printer are both applying colour management to your image, you could end up with bad colour outputs – for example, your reds look too pink. Check your colour settings in your editing software and your printer.
8. **Proofing and paper stock**
   Print a sample (proof) first to check your colours and see how they look on different types of paper – then you can adjust your colour if it's not looking the way you want it to. Different types of paper can affect how your colours print too.

Learn more about colour management issues here:

- Adobe: working with colour profiles
- Colour management theory
- Colour management guide

# Test yourself: colour systems – printing

## How did you go?

If you need to learn more about this topic, you can read this section again.

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# 3.5: Colour Systems- Pigments and Dyes

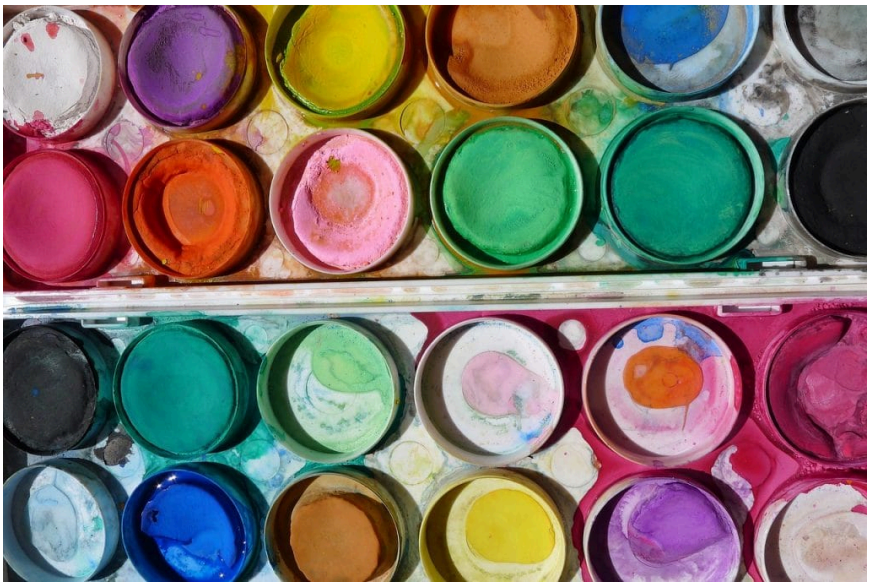


Figure 3.31 Artist's watercolour palette by Somraya via Pixabay, licensed under CC0.

The development, mixing and use of pigments and dyes throughout history, across all cultures, is an important part of understanding colour theory. From early human use of natural pigments made from ochres in the earth to synthetic colours developed in science labs, there are many interesting stories behind the colours we know and use today.

This section has information about where pigments and dyes come from, how they were developed, and how you can use them in your creative practice.

**What's the difference between a pigment and a dye?**

Pigments and dyes are the main types of colour materials (colourants) we use in art and design, and also in science and industry. A simple way to identify whether a colour material is a pigment or a dye is whether it is ***soluble*** or not:

- **pigments** are **insoluble** colourants – which means they can't be dissolved in water and are usually held together in some kind of "binder", which could be a liquid medium like oil, acrylic emulsion, or gum arabic, or formed into solid materials like pastels or pencils.
- **dyes** are **soluble** colourants – which means they can be dissolved in water. This is usually because the particles of a dye are much smaller than a pigment. A dye will chemically bond with the material it is absorbed into – like dyeing hair or fabric, and usually requires some kind of fixative called a "mordant" to help bind the dye to the material.

Pigments tend to sit on top of the materials they colour – like paint on a canvas. Some traditional painting methods also included **Tempera** – which used egg yolk as the medium for ground pigments – or **fresco painting**, where pigments were mixed with water and applied to wet plaster.

Many pigments are made from inorganic substances like rocks and minerals, whereas many dyes are made from organic substances like plants or insects, but there are exceptions to this rule. Most artists' paints are made from pigments, but inks can be made from either pigments or dyes. Inks can have different binders like shellac, acrylic emulsion or gum arabic.

Pigments usually hold their colour (**colourfastness**) better than dyes and don't fade as quickly in ultraviolet or visible sunlight (**lightfastness**). Have you ever had a carpet or curtains that partially faded in the areas that were exposed to the sun every day? Ultraviolet light can break the chemical bonds in coloured materials, which leads to fading over time. Some pigments are more lightfast than others. Some pigment and dye colours are called ***fugitive*** because they fade quickly – like the organic pigment

**madder lake**.

The lightfastness of coloured pigments was an area of experimentation for artists as early as the Renaissance, who noticed that certain pigment colours they were using in their paintings changed over time. Some colours faded from sunlight or got darker due to changes in the pigment structure. Some artists compensated for how colours would change over time by painting with very bright colours that they knew would fade or darken over time.

The image in Figure 3.32 shows how pigments can fade over time. The pigment used for the Prince's coat in this painting was originally bright red. It has faded due to light exposure for over 260 years. The other colours used remain closer to their original vibrance.



Figure 3.32. Portrait of George, Prince of Wales, later George III by Liotard. Image attribution: Jean-Étienne Liotard artist QS:P170,Q123757, George, Prince of Wales, later George III, 1754 by Liotard, marked as public domain, via Wikimedia Commons

Modern artists' paints today are generally more lightfast than early artists' pigments, thanks to research and experimentation by paint makers, but not many would be completely lightfast. That is why you might see valuable artworks in galleries and museums kept under special lighting conditions to minimise fading.

Read the following sections of this chapter to learn about the history and practical applications of paint pigments and dyes.

# Colour pigments: history and usage



Figure 3.33 Artist's palette by Rosa Bonheur via Wikimedia Commons, in the public domain.

## A timeline of colour pigments and dyes

Since pre-historic times, pigments have been used for painting and decoration. Pigments can be made from organic (plants and animals) or inorganic substances (minerals). Early pigments were made simply from grinding ochres found in earth and rocks into a powder that could be painted onto objects or bodies by mixing with water, oils or resins. Over time, cultural groups all over the world developed wider ranges of colours using more complex methods to extract colours, and they created various mediums for using these colours as paints and dyes.

Here is a list of many commonly known pigments and dyes, grouped roughly in chronological order by when they were first discovered and used. You can select any of these pigment or dye links to open a new tab with a Google search for each one, so you can begin your own research and learn more about what they are made from, where and when they were first discovered, and examples of their usage.

### Timeline of pigments and dyes

**Pre-history**

Red, yellow and brown ochres | Lamp black | Bone black | Bone white | White chalk | Woad



Figure 3.34 Pigment by Marco Almbauer via Wikimedia Commons, licensed under, CC BY-SA 3.0

**Traditional Australian Indigenous Ochres**

Watch this video by Aboriginal Elder*Yidumduma* Bill Harney to learn about traditional Australian Indigenous ochres that have been used for millennia by the *Yubulyawan* clan of the *Wardaman* people of the Victoria River region in the Northern Territory of Australia:

Media attribution: Red, White & Black Ochre, Paul Taylor on YouTube

**Antiquity**



Figure 3.35, Bucket of indigo, by gitane via Wikimedia Commons, licensed under CC BY 3.0.

Watch this video to learn about Egyptian blue:

Media attribution: Egyptian Blue: How an Ancient Pigment Could Save Lives, SciShow on YouTube

**Mediaeval**

**Ultramarine (Lapis lazuli) | Lead tin yellow* | Smalt | Vine black | Kermes | Peach black | Dragon's blood | Graphite | Lac | Gamboge* | Arzica (weld) | Brazilwood | Verdigris | Gall ink | Walnut | Stil de grain**



Figure 3.36. Cinnabar by H. Zell via Wikimedia Commons, licensed under CC BY-SA 3.0.

Watch this video to learn more about Dragon's blood (jump to 3:02 for the start of the lecture):

YouTube Video

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

Media attribution: Saturday University: Dragon's Blood and the Blood of Dragons Seattle Art Museum on YouTube

**Renaissance & Enlightenment**

**Burnt Sienna | Burnt umber | Copper resinate | Naples yellow (antimony)* | Van Dyke brown | Cobalt green | Potter's pink | Blue verditer | Mummy brown (*caput mortuum*) | Bistre | Logwood**



Figure 3.37. Cobalt Oxide Green pigment by Stephhzz via Wikimedia Commons, licensed under CC BY-SA 3.0.

Media attribution: Raw vs Burnt Earth Colors, Walcott Fine Art on YouTube

**Industrial Age and Modern**

**Prussian blue | French ultramarine | Chrome yellow | Chrome orange | Alizarin crimson | Cobalt blue | Cobalt yellow | Cobalt violet | Manganese violet | Scheele's green* | Emerald green* | Cadmium red | Cadmium yellow | Lemon yellow | Viridian | Cerulean blue | Zinc white | Titanium white | Mars colours | Indian yellow | Mauvine (aniline purple) | International Klein Blue | Fluorescent pigments | Phosphorescent pigments**




Figure 3.38. Stamp by Post of Aden via Wikimedia Commons, in the public domain.

Watch this video to learn more about the different types of white pigment used in artists' paints:

Media attribution: Artist's White paint: Zinc White Issues Malcom Dewey on YouTube

**Contemporary (late 20th Century +)**

**YInMn blue | Vantablack | MIT black | Pinkest Pink | Thermochromic pigments (colour-change with heat) | Photochromic pigments (colour-change with light) | Bio-pigments from bacteria | Pearlescent pigments | Interference pigments (different colours from different angles)**



Figure 3.39. Mas Subramanian, YInMn Blue – cropped(opens in new tab), CC BY-SA 4.0

Watch this video to learn more about the recently developed YInMn blue pigment and other colours created by Mas Subramanian:

Media attribution: A Beautiful New. Blue Makes Its Debut, Oregon Public Broadcasting on YouTube

**toxic pigment*

For more detailed information on pigments and how they are created and used, you can read this book, *Chromatopia* by David Coles, which has a detailed history of colour pigments and includes recipes for many colours you can make yourself:

Coles, David, and Adrian Lander. *Chromatopia: an Illustrated History of Colour*. Port Melbourne, Vic: Thames & Hudson, 2018

There's also a fun infographic: History of pigments by Korwin Briggs, that gives a humorous summary of selected pigments mentioned on this page.

**Other references:**

- Pigments through the ages: timeline
- Indigenous Australian pigments

# Mixing paint pigments

## Pigments are not pure primary colours

Chapter 1 covered a history of colour theory that included the development of different systems of primary colours – like RYB, RYGB, RGB and CMYK. Learning about primary colours can help us understand how to mix different colours, but it doesn't always help us to understand how **subtractive** colour mixing works in real and practical ways.

Most pigments (and dyes) are not pure primary colours. Pigments are made from substances that have a mixture of atoms that reflect a range of light waves. Paint mixing skills are important to learn in your creative practice.



When you first learn how to paint – whether with watercolours, acrylic paints, oil paints or other types of mediums – you will usually start with a basic set of pre-mixed artist-quality paint colours that can be used to mix a wide variety of different colours.

**A basic set of paint colours includes a mixture of warm and cool colours, and opaque and transparent colours.**

Some examples of this might include:

- Two different reds: **cadmium red** is an opaque, yellowish red, and **alizarin crimson** is a transparent, blueish red.
- Two different blues: **Prussian blue** is dark, cool, and transparent, and **cobalt blue** is intense, warm and opaque.
- There are also many types of **yellows** and **greens** that are cool or warm, opaque or transparent.
- There are also different types of **black** and **white** paint, and a range of earthy colours like **umbers**, **siennas, ochres** and **browns**.
- You might also have **violets** and **oranges** in your paint set that can't be mixed by combining other paint pigments.
- There are also other special paints that might have metallic or pearlescent pigments mixed with other colours or different paint mediums.

You can add to your basic paint set if you want more colours. Art materials suppliers have a large range of artists' paints with many colours to choose from. However, you probably don't need every colour available. Your particular colour palette will ultimately depend on the colours you want to use in your artworks. It's good to learn how to mix your own colours and avoid only using pre-made colours straight from the paint tube or pot.

If you are studying painting, you will learn how to mix the different pigments in your paint set to achieve a wide range of colours and avoid muddy or dull colours – unless you want neutral or subtle monochrome colours. You can learn to mix many **tints**, **shades** and **tones** of warm and cool greys or browns from your paints. Learn more about colour properties from the **Colour wheel** in this resource.

There are different paint mixing methods to create many colours in your artwork, such as:

- ***physical*** mixing of two or more paints to create a different colour
- ***glazing,*** which is overlaying transparent layers of different coloured paints to create a new colour
- or by using methods similar to the Impressionist painters, who placed small dots or patches of colour next to each other to give the ***impression*** of another colour when viewed at a distance.

**Artists' paints are pigments that are mixed with different mediums:**

- **Watercolour** paints are pigments mixed with gum arabic.
- **Gouache** paints are similar to watercolour but thicker and more opaque.
- **Inks** can be made with pigments or dyes and can have different mediums, like water, solvents, gels, gum arabic, or shellac.
- **Acrylic** paints are pigments mixed with an acrylic medium and there are different materials you can add to acrylics to make different textures for your paints.
- **Oil** paints are pigments mixed with an oil base, like linseed oil, but can also include waxes, pumice and solvents to create different thicknesses or textures.
- **Enamels** and **lacquers** are traditionally oil-based, with a hard, glossy finish – but you can also get acrylic resin-based versions.
- **Resin** – traditional resins were made from natural materials like tree sap. Synthetic resins use a two-part epoxy system that has a synthetic polymer and a hardener. Once combined, a chemical reaction occurs which turns the two liquids into a hard, solid material.
- **Encaustic** paint has a hot wax medium with pigments added to it.
- Other types of paint include: **Tempera** (egg yolk) and **Fresco** (wet plaster), which are not often used in contemporary creative practice because they must be made at the time of painting and are not practical to store or transport.

You can use more than one type of paint medium in an artwork, but it's important to learn which ones work together. For example, you can put oil paint on top of acrylic paint, but not the other way around. You can, in some cases, use different oil-based paints together, and different water-based paints together, but depending on the thickness or glossiness of the paint medium, this doesn't always work well. There is a lot to learn about painting methods and techniques!

**Why does red and blue make brown?**

Watch this video to learn more about colour pigment mixing...

Media attribution: Why Red and Blue Make Brown: Color Wheel Myth Dispelled, WriteArt on YouTube

You can also read this book to learn more about paint mixing:

Wilcox, Michael. *Blue and Yellow Don't Make Green*. [2nd ed.]. Bristol: School of Colour, 2001. Print

David Briggs has a very detailed and technical explanation of colour mixing on his website: *The Dimensions of Colour: Modern Colour Theory*. Read the section about Mixing of Paints for more information.



**The artist's palette as a colour system**

You can learn quite a lot about colour and painting techniques by studying the artworks of others. Some artists and art historians also like to delve deeper into an artist's methods and processes by studying the paint pigments that the artist has used, and how they arrange their painting palettes to mix colours before applying them to their paintings.

Photographer **Matthias Schaller** has created a series of photographs of famous artists' paint palettes – ***Das Meisterstück*** (*The Masterpiece*). He considers these to be a reflection of the artists' work and has created over 200 of these images. You can view some examples **on his website** and **in this Hyperallergic magazine article** .

Digital tools have also been used to analyse the basic colour palettes of famous paintings to help artists and designers learn about colour relationships – view some examples here:

The Art Squirrel: Colour Gamut Mapping for Painting

Experiments with Google: Art Palette

## Colour dyes: a (very) short history of dyes from around the world



Figure 3.41 Juana Gutierrez grinding indigo at the Porfirio Gutierrez family workshop in Teotitlan del Valle, Oaxaca, Mexico. Image by Thelmadatter via Wikimedia Commons, licensed under CC BY-SA 4.0.

Throughout history and across cultures and continents, dyes have been used for thousands of years to colour materials. Many dyes were originally used to colour textiles – fibre-based materials such as threads, yarns or fabrics that are woven or knitted and made from plant or animal fibres, such as cotton, linen, flax, hemp, grasses, wool, silk, human hair, etc. Dyes were also used to stain wood, pottery, and animal hides.

Dyes are different to pigments because they are soluble (they can dissolve in water) and traditionally were mostly made from organic substances (plants or animals). Dyeing processes can also be more complex than working with paint pigments because the dye must be absorbed and held fast in the material it is colouring. Different techniques were developed over time to bind dye colours with the material to prevent the dye from washing out or fading too quickly.

Many of the discoveries for improving dyes throughout history relate to developing chemical processes for creating more vibrant colours, and for creating colours that last longer, which includes ***lightfastness*** and ***colourfastness*** properties, and the ability to bind with materials they are absorbed into. The development of fixatives (known as ***mordants***) was a necessary innovation to prevent dyes from being washed out of textiles, enabling long-lasting colour. Some methods were more successful than others, and evidence has been discovered of ancient textiles that still have some colour from dyeing.

**Ancient discoveries**

Archeologists have discovered examples of dyed textiles that date back to Neolithic times. One example is from around 10,000 BCE, in the Timna Valley, South Israel, where ancient copper and ore mining sites have been uncovered. [1].

Another archeological example is the discovery of 30,000 year-old flax textiles found in Dzudzuana cave, located in the foothills of the Caucasus region in Georgia, Europe. The flax was dyed in many different colours, including "yellow, red, blue, violet, black, brown, green and khaki."[2]

The ***Silk Road*** was an ancient trading route that ran from the Roman civilisation on the Mediterranean, through Afghanistan, the *Levant* and India, to the Xi'an region in northern China. This route was over 6,400 kilometres long! It was a pathway for trading between east and west cultures in many products such as spices, textiles, and precious metals. It was also the pathway for trading **dyestuffs** and knowledge about dyeing processes., accessed 03/01/2023, https://www.britannica.com/topic/Silk-Road-trade-route ">[3]

Because of the Silk Road, and ancient ***maritime*** trade routes, many cultures had access to dyes that were not made from plants native to particular areas – including indigo, woad, saffron, madder, and safflower. Here are some (very) short stories about the history of selected dyes from locations around the world:

**China and Japan**

In ancient Chinese silk production, colouring the thread began right from the first stage when the silkworm creates silk thread to form a cocoon. By feeding the silkworm white garden mulberry or wild mulberry leaves, the silk produced could be either white or yellow. Creating different coloured silk threads often involved bleaching it first by boiling threads in the ash of *Lian* tree fruit. Blue dye was made by fermenting indigo, black from iron vitriol, red from madder root or safflower, and yellow from *Jinzi* fruit.

The Ming (1368–1644) and Qing (1644–1911) Dynasties in China created very detailed records of types of dye and the dyeing methods and processes used. These records are an important historical resource for understanding how different natural substances were used to achieve the diverse and vibrant colours we associate with Chinese silk and other textiles.[4]

Japan has a long tradition of dyeing materials such as textiles, paper and wood, going back 2000 years. There are also records going back to the 7th century that document textiles dyed with red, blue, and other colours. These dyes were made from natural materials native to Japan, but also those that came via the Silk Road, maritime trade, and from the influences of Chinese and Korean textiles and dyeing methods. Evidence exists of textiles dyed with vermilion, sappanwood, cinnamon and ***Gunjyo*** – a blue pigment made from mining a mineral ore that had copper in it., accessed 04/01/2023, https://www.aic-color.org/resources/Documents/jaic_v5_gal2nar.pdf ">[5]

Japan is also known for its indigo dye and textiles called ***Aizome***. Indigo was introduced to Japan in the Heian period around the 7th Century CE. Since that time, techniques for creating indigo textiles have developed to become culturally significant, and Japanese indigo textiles are highly valued around the world.

YouTube Video

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

### South-East Asia

Although **Batik** (wax resistance dyeing) is historically found in many places around the world, its origins in Java, Indonesia, are significant. Indonesian Batik was recognised by UNESCO in 2009 and placed on the Representative List of the Intangible Cultural Heritage of Humanity.

Watch this video to learn more about the history and techniques of Batik:

YouTube Video

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

Media Attribution: What is Batik? Historically Speaking, Ours For All on YouTube

### India

India's ancient history of dyes is significant. Not only did they produce many dyes and techniques for achieving vibrant colours, but they also developed mordants and processes to fix the dyes, which were closely guarded secrets for a long time. Indian textiles were highly prized across Europe. The name "Indigo" is a reference to India, where the plant *Indigofera Tinctoria* was grown, although it was also found in much of Asia and parts of Africa too.

The ancient Sanskrit texts, known as the **Vedas** (meaning "knowledge"), are the oldest Hindu texts known to exist – from around 1500-500 BCE. These contain details about textiles and clothing worn at different times of the year or at religious ceremonies, with reference to multiple colours. From these texts, we know that Indian dyeing techniques for creating vibrantly coloured fabrics existed around that time.

Tie-dye, known as **Bahndani** (meaning "to tie up"), is also accredited to Indian culture, going back thousands of years. Other techniques like **Batik** and **Ikat** were also used with dyed yarn or woven fabrics. India was one of the first places to produce cotton in large quantities, and produced many dyed cotton textiles that were traded in other countries.

This video discusses the complex and problematic history of Indigo dye beyond South Asia (see also North America below for more details about the creation of blue jeans):

YouTube Video

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

Media Attribution: A Short History of the Colour Indigo, National Gallery UK, on YouTube

**Egypt and Persia (North Africa & Middle East)**

Ancient Egyptians wore mostly white linen textiles, but they also dyed fabrics in a range of colours. They used Madder for red dye, Safflower for yellow, Indigo or woad for blue, and Murex snails for purple (Tyrian purple was originally made by the Phoenicians).

Ancient Persians also developed rich colours using dyes like *runas* (madder), *red grain* (kermes or cochineal beetles), walnut, *neel* (indigo), vine leaves, and other plant materials. Methods for dyeing wool and silk with these diverse colours coincided with the creation of woven and knotted carpets – something we still associate with Persian culture today.

The first carpets date back over two thousand years and were created by nomadic tribes and royal courts. Each group would have their own designs and colours which reflected the history and symbolism that was important to the creators. Carpets created during the Safavid Empire (1501-1736) are world famous for their intricate designs using intense colours, and there are many examples held in museums around the world – here is one example shown in Figure 117.



Figure 3.42. Hunting Carpet made by Ghyath ud-Din Jami, Wool, cotton and silk, 1542–1543, Museo Poldi Pezzoli, Milan. Image attribution: Ghyas el Din Jami – Weaver (Persian) Born in North-West Persia. Died in North-West Persia. Google Art Projectでのアーティストの詳細, Ghyas el Din Jami – Tabriz (?) – Google Art Project, marked as public domain, more details on Wikimedia Commons

Watch this video to see the restoration of a Safavidic carpet:

YouTube Video

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

Media Attribution: Conserving the Emperor's Carpet, The Met on YouTube

**West and South Africa**

There are many different types of dyes and textile designs that come from the many countries and regions in Africa. Groups develop their own designs with colours that have symbolic and cultural meanings. Techniques such as batik and tie-dyeing developed in African cultures, and common dyes included indigo, kola nut (brown), annatto (a yellow and orange colour), and earth colours.

Visit this website: *The Fabric of Africa* , on Google Arts and Culture, to see many beautiful and diverse examples of African textiles from different parts of Africa.

This video shows the work of artisans who practice West African (Nigeria, Ghana and Mali) ancient textile traditions: Adire, Adinkra and Bogolan 'Mud cloth'. (19 minutes)

YouTube Video

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

Media Attribution: West African Textiles, BurroGrande Films on YouTube

**Greek, Roman and other Mediterranean civilisations**

Ancient Greek, Roman and neighbouring civilisations used a range of plant and animal dyes to create coloured textiles. Plant dyes included crocus sativus (ochres), madder, woad, weld (yellow), walnut hulls, oak gall (brown and black), orchil lichen (pink/purple), alchanet (red), and saffron crocus (yellow).

Animal dyes included kermes beetles (red/cochineal) and seashell creatures such as Hexaplex trunculus, Bolinus brandaris, and Stramonita haemastoma, which created a purple dye similar to the Murex sea snail that was used by the Phoenicians and Romans to create Tyrian purple., accessed 21/12/2022, https://artextiles.org/en/content/dyes ">[6].

Watch this video for more details about how Tyrian purple was created:

YouTube Video

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

Media Attribution: Tyrian Purple | History of Colours, Little Art Talks on YouTube

**British Isles and North/West Europe**

Civilisations from the British Isles and Western Europe used a range of plant materials to create diverse dye colours. Despite being grown across southern Europe and the Caucasus, Britain is primarily known for its woad (*Isatis Tinctoria*) dye, perhaps because of the legends of **Boudicca** and the **Iceni** tribe, who painted their faces with the blue dye. The Celts also used it as body paint and possibly tattoo ink – Romans referred to the Celts as "Picts" (Picti means painted people in Latin) because of their blue tattooed bodies. Evidence of plant materials goes back as far as the Iron Age, and the plant was used for medicinal purposes as well as dye.

Vikings created their own dyes from local plant materials, but they also traded for colours like woad, indigo, madder and cochineal to create more vibrant colours than they could make from local ingredients. They used small amounts of dyes to create decorative edgings on their textiles rather than dyeing entire fabrics. They also used a range of available mordants to fix the dye colour, such as iron, tin, copper, and alum.

Watch this video to learn about traditional dyeing methods, including the use of different mordants that would have been available during the Iron Age (1200 – 550 BCE) in Europe.

YouTube Video

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

Media Attribution: Iron Age Dyes: Woad, Weld & Madder, Sally Pointer on YouTube

**North America**

Many plants were used by Indigenous Northern Americans to create a wide range of dye colours, such as sumac, bloodroot, alder, cottonwood and black walnut. Early western colonisers noted that native coloured textiles tended to fade quickly, so it is thought that coloured dyes were used in a ***direct*** or ***substantive*** dyeing method where mordants were not used. accessed 02/01/2023, https://www.fs.usda.gov/wildflowers/ethnobotany/dyes.shtml ">[7]

**Blue Jeans, Denim and Dungarees**

'Bleu de Gênes' was made from "bastard indigo", a plant related to *Indigofera,* called *Amorpha Fruticosa*. It was used to produce a blue dye for sail cloth that became known as 'Bleu de Gênes' (the blue of Genoa – from Italy), shortened to "***jeans***".

'Tenue de Nîmes' (Clothes from Nîmes – from France), short name "de Nîmes", was a textile developed in the 17th century that had a twill weave using one light thread and one dark thread, so the fabric was dark on the outside and light on the inside. The English and Americans eventually turned the name of this textile into what we now know as '***denim***.', accessed 01/01/2023, https://medium.com/@tsbojer/the-history-of-indigo-dyeing-and-how-it-changed-the-world-35c8bc66f0e9 ">[8].

The term "dungarees" most likely comes from a sturdy cotton textile made in Dungri, Gujarat, India, that was often coloured with indigo dye.

Although they originated in Europe and India, these blue textiles are now associated with American culture due to the production of the clothing item we call "blue jeans". In 1853 a German immigrant, Levi Strauss founded his company in San Francisco, USA, which stocked "denim" fabric. In 1873, Latvian emigrant and tailor Jacob Davis and Levi Strauss patented and manufactured the "XX" pants, which became known as Levi 501s. These are claimed to be the world's first blue jeans. These jeans had metal rivets on the pockets and a button-fly, which made them tough and suitable as workwear.

Claims that Levis were the first “blue jeans” are disputed by some historians who point to evidence that similar garments were first created by enslaved black people working the indigo and cotton plantations in Southern states. These enslaved plantation workers needed tough working clothes for the hard labour that was part of plantation life. They had ready access to the cotton that came from the plantations to produce the fabric, and they had the cultural knowledge from their African homelands to know how to dye the fabric with indigo – which also had anti-fungal and antibacterial properties.

According to these historians, Davis and Strauss merely added metal rivets to their work pants design and patented the product. , accessed 23/12/2022, https://www.phillytrib.com/commentary/michaelcoard/enslaved-blacks-invented-blue-jeans/article_57de5262-5b78-534d-a133-bfc406f87a78.html ">[9]

Watch this video for an overview of the origins of blue jeans:

YouTube Video

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

Media Attribution: Where Did Blue Jeans Begin? | Riveted: The history of Jeans, American Experience | PBS on YouTube

**Central and South America**

Indigo was used in Central and South American civilisations. There is evidence that it was used in the Andes as far back as 6200 years ago – which predates its use in India, Egypt and other ancient civilisations.[10]

**Maya blue** was “made by burning incense made from tree resin and using the heat to cook a mixture of indigo plants and a type of clay called palygorskite”. The process of mixing the indigo and tree resin with clay created a long-lasting colour that didn’t fade. In fact, the discovery of artefacts containing this dye has led to physicists developing their own modern version that is resistant to fading and weathering. accessed 03/01/2023, https://phys.org/news/2010-07-ancient-mayans-modern-proof-dye.html ">[11].

Relbun (similar to madder) was used to create red dye over 2000 years ago, but the advent of using cochineal beetles around the 5th Century CE changed dye production in places likes Mexico and Peru. Cochineal became a valuable commodity used for trading and was worth as much as silver to Spanish colonisers. For many years, the Spanish claimed that cochineal was a seed and hid the fact that it was an animal product – to prevent others from breaking their trading monopoly.

Watch this video to learn more about cochineal:

YouTube Video

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

Media Attribution: Cochineal Origins, Harvard Museums of Science and Culture on YouTube

**Australia**

Australia has Indigenous cultures that have used dyes from a variety of plants, minerals and animal products to colour fibres used for textiles, basket weaving, knotting, and other products for many thousands of years. Different language groups around the continent developed their own knowledge bases using different methods and diverse local materials they found in their geographic locations.

Sally Blake, an Australian artist based in Canberra, studied eucalypts at the Australian National Botanical Gardens, specifically for their dye properties. She has produced an extensive database of Eucalyptus dye colours, which shows the wide range of colours achieved by using the different eucalyptus species, different parts of the plant such as leaves or bark, use of different mordants such as alum, iron or copper, and use with different textiles – wool, silk and linen.

Select the link below to watch this video on YouTube, which shows the bundle dyeing technique using native plants to colour fabric – from Boon Warrung, Wurundjeri and Ngarluma Country. Included are eucalyptus leaves, for yellow, grey or purple colours, eucalyptus bark for purples, and acacia leaves, which can create orange or red colours:

**Create unique coloured patterns on fabric using native plants | My Garden Path | Gardening Australia on YouTube**



Figure 3.43. *Eucalyptus tereticornis* buds, capsules, flowers and foliage, Rockhampton, Queensland. Image attribution:L Ethel Aardvark, Eucalyptus tereticornis flowers, capsules, buds and foliage, CC BY 3.0

## Further resources (RMIT Library search)


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# Colour dyes: methods and processes



Figure 3.44. Wool coloured with natural dyes by Himalayan Weavers. Image by Alamcsd at wts wikivoyage via Wikimedia Commons, in the public domain.

Early dye processes involved soaking and boiling textiles in coloured solutions made from substances such as roots, berries, bark, leaves, wood, fungi, and animal products in a **direct** or **substantive** dyeing method. However, these dyed textiles may not have had a very lasting colour. It was eventually discovered that different methods could be used to create stronger colours and to fix the colours so they didn't fade or wash out so quickly.

Some methods used **fermentation** to create a strong colour, as with Indigo, woad and madder. For example, the indigo plant isn't actually blue. The blue colour only comes from soaking the leaves to release the indican amino acid, which is then fermented by other plant enzymes – a process called *indoxyl*. It is left to dry in the air, which oxidises it, creating a blue colourant. An indigo dye bath looks green – it's only when the dyed material is brought into the air that it oxidises and turns blue before your eyes.

Dyes like Madder can also be turned into pigments by "laking" (hence the term "madder lake") – which means the dye is combined with a mineral salt to produce an oil-soluble substance that can be used like a paint pigment.

A **mordant,** which was often a type of mineral salt like sodium chloride (table salt), alum or copper vitriol, or another substance like vinegar, or even stale urine, was used to fix the dye so it wouldn't wash out of the fabric.

Many of these processes smell terrible!

Synthetic dyes changed the complex and labour-intensive methods of natural dyeing. Many synthetic dyes are made from petrochemical processes, or from other chemicals that can be manufactured in large quantities in industrial settings like factories, and are relatively inexpensive in comparison with some natural dyes. There are many types of synthetic dyes, such as reactive dyes, disperse dyes, base and acid dyes, sulphur dyes, aniline dyes, azo dyes etc. Different types of dyes and dyeing methods suit different types of materials.

Most dyeing processes today are for textile production. The three types of fibres that are commonly used for textiles today are:

- **Cellulose**: cotton, flax, linen, hemp, viscose/rayon/modal (made from bamboo or other plant fibres)
- **Protein**: wool, mohair, silk
- **Synthetic**: nylon, polyester, acrylic, acetate

Here are some of the common dyes and dye techniques used in industry today:

**Reactive dyeing method**

Fibre-reactive dyes are commonly used for fabrics made from cotton, linen, viscose wool and silk. This type of dye “reacts” with the fibre it is colouring because of a *chromophore* that creates a chemical link with the fibre, binding the colour to it. The colour then becomes part of the fibre. It usually has a good level of colour fastness. Cold water dyes like ***Procion*** dyes are fibre reactive and use soda ash in the dyeing process. They do not need mordants and are non-toxic.

**Disperse dyeing method**

This is a high-temperature dye made from fine, insoluble dye particles that are from a *suspension*. They are suited to hydrophobic fibres (they don’t absorb water) such as synthetics.

**Direct dyeing method**

Also called **Substantive** dye, this method is used for cotton, and although lightfast, washes out easily. It’s called “direct” because the dye is absorbed into the fibres without help from other chemicals, such as mordants.

**Vat dyeing method**

Vat dyeing is still used for some textiles. Natural Indigo is one of the original vat dyeing methods, where textiles are soaked in the vat until the right colour strength is achieved. This may require more than one soaking in the vat to deepen the colour.

**Basic and acid dyes**

Basic (alkaline) and acid dyes are water-soluble dyes. Basic dyes are used for acrylic fibres, and acid dyes are used for wool, silk and nylon fibres.

**Sulfur dye**

Sulfur dyes are used for cotton and other cellulose fibres, and also for blended fibres that contain cotton mixed with polyester or acrylic fibres.

**Chrome dye**

Chrome dyes were synthetic dyes developed in the early 20th Century and commonly used on wool for carpet manufacture, with the use of a chemical to allow the dye to penetrate the fibre. They have good light and colour fastness properties.

**Azo dye**

Azo dyes are synthetic dyes used in a variety of products, including textiles, leather, foods, cosmetics and carpets. Certain Azo dyes are considered harmful because they can break down into a carcinogenic compound called Aromatic Amines (including benzidine), and can trigger toxic effects such as allergic reactions, tumours, and endocrine disruptions. Although Azo dyes are banned in the UK and restricted in the USA, they are allowed in Australia., accessed 08/01/2023, https://www.productsafety.gov.au/products/chemicals/azo-dyes ">[1]

Learn more about the dangerous history of synthetic dyeing methods and processes from this video:

YouTube Video

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

Media Attribution: Fashion that SLAYED!? A History of Fabric Dyes (and all the damage early chemical dyes did), Emily Snee on YouTube


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# Test yourself: is this a feature of pigments or dyes?

## A multiple choice quiz to test your understanding of pigments and dyes

**(5 minutes or less)**

**How did you go?**

If you need to learn more about this topic, you can read this section again: 3.4 Colour systems: pigments and dyes

# Colour dyes: synthetic colours and sustainability

## Impact of synthetic colour development

Egyptian blue[1] was one of the first synthetically created pigments, made from crushed blue glass (silica and copper) over two thousand years ago. Although synthetic pigments and dyes have existed throughout history, it wasn't until the industrial era that there was a boom in chemical synthetic colours that were relatively cheap and easy to make and therefore used in industry for the mass production of paints and dyes, which were used in products like textiles, paper, plastics, and many other materials.

**Prussian blue** was the first chemical synthetic colour accidentally created by Johann Jacob Diesbach in 1704. One of the first synthetic dyes to be mass-produced was a mauve colour called **Mauveine** (also known as **Aniline purple** and **Perkin's mauve).** It was also accidentally discovered by William Henry Perkin in 1856 while he was trying to create the chemical ***quinine,*** which was used at that time for the treatment of malaria.

**Mauvine**
#8D029B

Many of the synthetic colours we now use in artist paints and industrial practices (Figure 3.45) are safer and cheaper options than the equivalent pigments from the past. Older colours like realgar, vermilion and emerald green are highly toxic due to their chemical compounds which include lead, mercury, arsenic or other dangerous materials that are harmful to human health. Many people became ill or died from the creation and use of pigments and dyes containing these toxic substances. Learn more about this in Special colours, controversial colours and interesting facts on the next page.

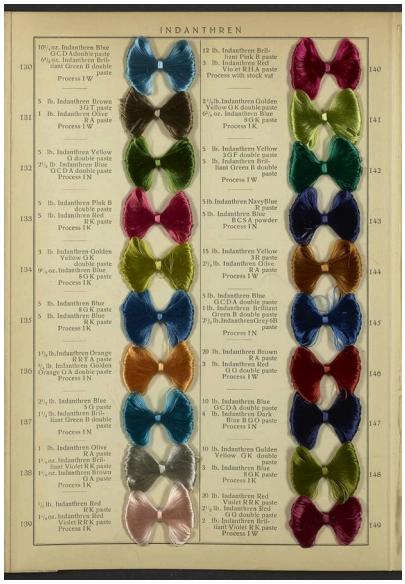



Figure 3.45. Indanthren Dyeings on Rayon (Viscose) Yarn by Science History Institute via Wikimedia Commons, in the public domain.

**Hair dyes**

People have been dyeing their hair for thousands of years too! Ancient cultures used natural dyes like Henna, Indigo, Tumeric, Senna, Walnut and Cochineal to dye their hair a range of colours, such as red, orange, yellow, black, brown, or even green. Some ancient people like the Celts also bleached their hair with lime or other substances that would strip the hair of colour.

Natural dyes can create unpredictable results because they may have different amounts of reactive substances and colourants, and they also tend to fade over time. Some products, like “black henna” (which is not actually henna), can cause extremely serious allergic reactions and are banned in many countries.

Synthetic hair dyes were first developed in the late 19th century. French company L’Oréal was the first company to manufacture synthetic hair dyes around 1907, and the German company Schwarzkopf was the first to create at-home hair dyes in 1947. Today, hair dye products are a huge industry and are available in a wide range of colours – in fact, all the colours of the spectrum (Figure 3.46), as well as natural colours and treatments that bleach or lighten the hair.

There are temporary and permanent dyes that can be used to colour hair (including facial hair). However, some colours are more lightfast than others, and even colours classed as “permanent” can still wash out or fade – especially colours like violets, blues and greens, which are more *fugitive* dye colours. You can also now get hair dyes that fluoresce in UV light – known as ***blacklight-reactive*** hair dyes.



Figure 3.46. Pink hair in Harajuku by Jacob Ehnmark via Wikimedia Commons, licensed under CC BY 2.0.

## Sustainability, waste and pollution from making and using dyes

Dye production and usage (both natural and synthetic dye) has had a problematic history due to the use of petrochemicals to create synthetic colours, the use of water in the dyeing process, and the creation of wastewater from the washing process.

Since the advent of industrial and synthetic dye-making processes (Figure 3.47), and industrial use of dyes for producing textiles and other materials, industries working with dyes have caused a lot of pollution and used great quantities of clean water.

New methods are being developed that seek to reduce waste in dye production and usage, to create a more sustainable industry. This also impacts broader issues in the fashion industry relating to clothes wastage and sustainability.

These articles have more information on this topic:


- Paillié-Jiménez M E, Stincone P, Brandelli A 2020, "Natural Pigments of Microbial Origin", *Frontiers in Sustainable Food Systems*, Vol 4, 2020, viewed 07/12/2022, <https://www.frontiersin.org/articles/10.3389/fsufs.2020.590439>, DOI=10.3389/fsufs.2020.590439, accessed December 21, 2022
- Bealle, A. (2020) *Why clothes are so hard to recycle*, *BBC Future*. BBC. <https://www.bbc.com/future/article/20200710-why-clothes-are-so-hard-to-recycle>, accessed: January 3, 2023
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ISSN 2452-0721, https://doi.org/10.1016/j.biori.2019.09.001.<>, accessed 04/01/2023




Figure 3.47. Vats for dyeing silk cloth. New York Public Library via Wikimedia Commons, in the public domain.

1. Pradell, T., Salvado, N., Hatton,G.D., Tite, M.S., 2006, "Physical Processes Involved in Production of the Ancient Pigment, Egyptian Blue", *Journal of the American Ceramic Society*, Volume89, Issue4, April 2006, pp. 1426-1431, https://doi-org.ezproxy.lib.rmit.edu...6.2005.00904.x, https://ceramics.onlinelibrary.wiley.com/doi/abs/10.1111/j.1551-2916.2005.00904.x

## Special colours, controversial colours and interesting facts

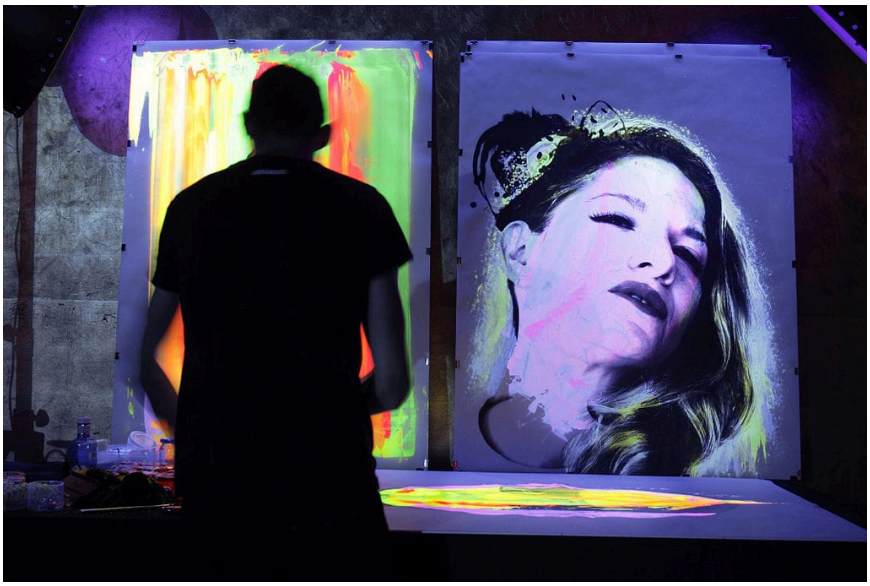


Figure 3.48. Painting with fluorescent colours which glow under black light. Beo Beyond via Wikimedia Commons, licensed under CC BY 3.0.

The history and stories of some pigments and dyes are curious, and sometimes controversial. Here are a selection of interesting colours and fun facts:

**Topics covered**

- Luminescent and special effects pigments and dyes
- Trademarked colours

## Luminescent and special effects pigments and dyes

In Chapter 2, the page about Luminescence explains the chemistry of fluorescence and phosphorescence. But making fluorescent and phosphorescent pigments involves complex processes that involve both **chemistry** and **physics**. There are also special effects pigments that change colour under different conditions.

There are different kinds of fluorescent and phosphorescent colourants that can react with UV light as well as visible sunlight. Some can even react with infrared light waves. Capturing fluorescent or phosphorescent effects requires very specific treatment of the pigment particles. Theses types of pigments must be mixed with a stable medium that can be used as a paint or printing ink that will last.

### Fluorescent pigments

Fluorescent pigments (See Figure 3.48 at the top of the page) can be made from organic or inorganic substances. The pigments don't fluoresce in their solid state, but if they are dissolved in a **thermoplastic** or **thermoset carrier resin** and then ground into a fine powder, they become fluorescent pigments [1].

### Phosphorescent pigments

We are familiar with phosphorescent pigments that are used as "glow-in-the-dark" paints and pigments that can be mixed with plastics (Figure 3.49). These pigments are made from phosphors that capture light (photons) and store the energy, emitting it slowly as photons over a period of time after light exposure. An example of this would be a glow-in-the-dark toy that absorbs sunlight or even artificial light, and then releases it at night-time or when all lights are removed.

**Copper-activated zinc sulfide**, called ***GS phosphor***, is often used as the phosphor in toys, whereas a more powerful substance like strontium aluminate is used for road signs, road surface lines, and warning signs. Phosphorescent pigments can be mixed into paint mediums, waxes or plastics. They have many different uses.

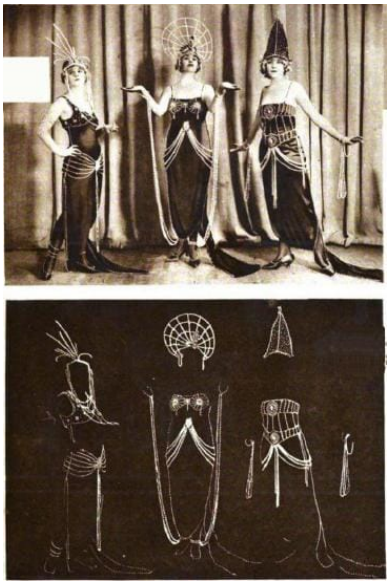


Figure 3.49. The "pearl scene", New York City, 1921.A dance troupe wears costumes covered with pearls covered with phosphorescent paint. The lights in the theatre are turned off, and the pearls glow. Eric A. Dime via Wikimedia Commons, in the public domain.

**Photochromic and Thermochromic dyes and pigments**

**Photochromic** pigments and dyes have a reversible (or sometimes irreversible) colour change when exposed to light rays. Some can go from transparent to coloured, as in optical lenses (transition lenses) that get darker when worn outside in sunlight, and become clear again when entering a darker space. Other common examples can be found in nanofibres in smart textiles, in toys, and as UV warnings for sunburn.

Photochromic pigments contain microencapsulated photochromic dye mixed into a synthetic resin. The colour change happens when light exposure triggers a chemical reaction that changes which light waves are reflected and absorbed, thus changing the colour. When the light is removed, the chemical reaction dissipates and the pigment goes back to its original colour.

**Thermochromic** pigments have a reversible (or sometimes irreversible) colour change when heat is applied to the pigment. Applied heat triggers a chemical reaction to occur that changes the light waves that are reflected and absorbed, thus changing the colour. Examples include textiles, objects like coffee cups, toys, and food packaging. Colour change labels can detect if food packages have been exposed to temperatures that might spoil the edible contents. Figure 3.50 shows a short video clip of a thermochromic coffee mug changing colour when boiling water is poured into it.

**** insert a coffee mug video **

**Pearlescent and Interference pigments – structural colouration**

Pearlescent and interference pigments are usually created with complex and multi-layered paints that appear to have different colours when viewed from different angles.

You might have noticed similar phenomena like oil slicks, soap bubbles and peacock tail feathers that appear to have rainbow colours or two or three different colours when moving. It's an optical phenomenon where surfaces appear to change colour depending on the angle they are viewed from.

**Iridescence** (also known as ***goniochromism*** – from the Greek **gonia** = angle, **chroma** = colour) is the name for this effect.

This example in Figure 3.51 is called *ChromaFlair* – it's a pigment for automotive paint. You can see in the image that the paint finish on this car appears to be different colours depending on the angle you are viewing the surface from. The curves of the car body show different colours because they are at different angles to the camera. This type of effect is also called Structural colouration .




Figure 3.51. TVR Tuscan Speed Six car painted with ChromaFlair interference pigment. Image attribution: Mytho88, TVR Tuscan 01, CC BY-SA 3.0 from Wikimedia commons

## Trademarked colours

There are certain colour pigments that have been developed by individuals or organisations who have tried to limit the use of their colour with trademarking. Many companies have tried to trademark their logo colours or signature product colours, but this has only been partly successful. One successfully trademarked colour is Tiffany Blue , which is a colour developed by Pantone for the jewellery company Tiffany & Co. This colour can't be used by anyone except Tiffany for their packaging.

### Yves Klein: International Klein Blue

Around 1960, French artist Yves Klein collaborated with artist paint maker Edouard Adam to develop a deep and vibrant blue pigment with a matte, powdery quality, which is similar in colour to a synthetic ultramarine. Klein called the pigment ***International Klein Blue (IKB)*** and he used the pigment mixed with resin in many monochromatic artworks – some abstract (Figure 3.52), and others figurative, often using naked female models covered in the paint who would then press their bodies onto canvas. Klein registered the pigment so that others couldn't use it. However, Adam still sells this pigment today under the name ***Médium Adam 25.***

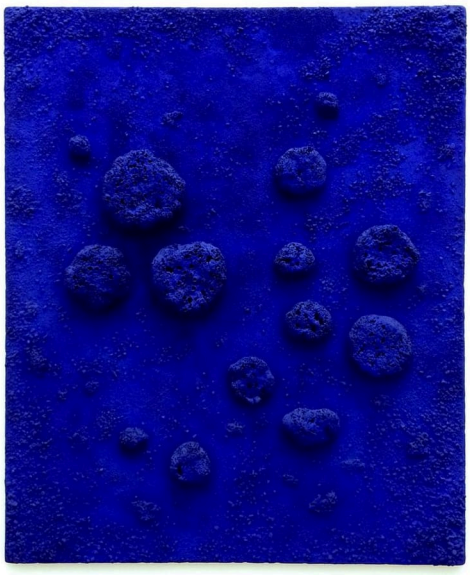


Figure 3.52. Artwork *L'accord Bleu* by Yves Klein, 1960, using International Klein Blue pigment. Image attribution: Jaredzimmerman (WMF), L'accord bleu (RE 10), 1960, CC BY-SA 3.0

### Vantablack (Anish Kapoor controversy)

Sculptor Anish Kapoor bought exclusive rights to use the paint Vantablack, which was developed by Surrey NanoSystems in 2014 and originally created for use in military and astronautical industries. Vantablack was the "blackest" black pigment at that time, which could absorb up to 99.965% of light. This means that it barely reflects any light, so objects that are covered in this pigment look like a void or black hole (Figure 3.53).

Kapoor's actions caused controversy in the art world because a lot of artists and critics don't think that art materials should be restricted. Many believe materials like this should be available for anyone to use.



Figure 3.53. A sample of Vantablack pigment covering aluminium foil. Image attribution: Surrey NanoSystems, Vantablack 01, CC BY-SA 3.0

**Stuart Semple's Pinkest Pink and other *liberated* colours**

Multidisciplinary artist Stuart Semple has made it his mission to make quality artist pigments that are available to everyone. He dislikes the proprietary way that Kapoor and others attempt to limit who can access certain artist pigments. Semple's pigment PINK: ***The world's pinkest pink*** was initially created as a reaction to Kapoor's Vantablack. Semple's Pinkest Pink can be used by everyone except Anish Kapoor. You can purchase this pigment by agreeing to the following:

> **Note: By adding this product to your cart you confirm that you are not Anish Kapoor, you are in no way affiliated to[sic] Anish Kapoor, you are not purchasing this item on behalf of Anish Kapoor or an associate of Anish Kapoor. To the best of your knowledge, information and belief this paint will not make its way into that[sic] hands of Anish Kapoor.*

However, Kapoor did get access to the Pinkest Pink pigment and posted a photograph online with his middle finger covered in the pink powdered pigment. The feud continued with Semple creating Black 2.0 and then Black 3.0 pigments which rival Vantablack as the "blackest black", and more recently, he has created a range of pigments with sparkling, pearlescent or interference pigments which are freely available to purchase from his online store. He has also made a copy of International Klein Blue that he calls ***EASY KLEIN – IKB Incredibly Kleinish Blue*** , and a copy of Tiffany Blue called Tiff Blue.

Read this related article in The Collector online magazine .



Figure 3.54. Vibrant pink powdered pigment (not Pinkest Pink) by Honey Fangs via Unsplash, licensed under CC0.

**MIT black and Musou black**

In 2019, MIT produced a pigment that is even blacker than Vantablack, called MIT black . It can absorb even more light than Vantablack – 99.995% – and is also more durable. It's made from vertically aligned carbon nanotubes (CNTs), which are grown on aluminium.

Recently, another very black paint called **Musou Black** was developed in Japan. It absorbs 99.4% of light, making it the darkest black paint that is available on the market. This paint comes as a water-based acrylic, and anyone can purchase it online.

Watch this video to see what Musou black looks like in the real world (8 minutes):

YouTube Video

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

Media attribution: I Painted My Entire Room With Musou Black—The World's Blackest Paint, by The Action Lab on YouTube

1. The Chemistry and Physics of Special-Effect Pigments and Colorants for Inks and Coatings, Paint and Coatings Industry, https://www.pcimag.com/articles/85016-the-chemistry-and-physics-of-special-effect-pigments-and-colorants-for-inks-and-coatings

## Problematic colours

Some pigments and dyes have a problematic history due to how they were created and used, which was harmful to humans or animals, or because they contain toxic substances that poisoned people who were working with them, causing serious health problems and death.

## The Library of Rare Colours

View this video to learn about a rare collection of pigments (including some problematic ones): the Forbes Pigment Collection at Harvard Art Museums in the USA (5 minutes)

YouTube Video

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

**Media attribution: The library of rare colours by Tom Scott on YouTube**

## Problematic and dangerous colours

Read on to learn about some problematic pigments and their stories...



**Mummy brown**

Also called *Mumia* or *Caput Mortuum* (Latin meaning *dead head*), Mummy brown was a rich brown pigment made from grinding up real mummified humans and animals. Eventually, the supply of mummified bodies declined, and people began realising how the pigment was made and found it distasteful, so it was no longer produced or used. The modern artists' pigment called Mummy brown is made from inorganic earthy substances.

Note: There is another colour known as Caput Mortuum Violet, which has a more purplish, mauve-brown colour, like dried blood. It was made from iron oxide and used by the Romans.

Read more about Mummy brown in this Harvard Museum article

Figure 3.55. Painting by Martin Drolling, 1815 showing use of Mummy brown pigment. Image attribution: Martin Drolling artist QS:P170,Q3295410, Martin Drolling – Interior of a Kitchen (detail) – WGA6679, marked as public domain, more details on Wikimedia Commons. Select image to enlarge.



**Indian yellow**

Indian yellow has a controversial history. It was claimed that the pigment was produced from the urine of cows that were fed only mango leaves, but this story was disputed by some sources. The story claims that cows were malnourished and sickly as a result of the diet and that this practice was outlawed in 1908 due to animal cruelty. Investigations into this story revealed no evidence to support it. However, more recent chemical analyses of pigment samples from the past, going back to 1400 CE, have shown that in some cases, the origin of this pigment was from cow's urine, so historically, the pigment *was* produced this way. Today Indian yellow (Figure 3.56) is made by synthetically producing euxanthic acid – which is the main component.

Learn more about Indian yellow

Figure 3.56. Indian Yellow Pigment. Image attribution: Shisha-Tom, Indisch-Gelb, CC BY-SA 3.0. Select image to enlarge.




**Scheeler's green and emerald green (also known as Paris green – Figure 3.57)**

These pigments are very toxic due to the main ingredient, which is arsenic. This type of green paint and dye became popular as wallpaper and as a textile colour for women's dresses and accessories in the Victorian era. It soon became clear that emerald green fabric and furnishings caused terrible health problems associated with arsenic poisoning, such as skin blisters and sores, nausea and vomiting, and death. Despite this, many still wore the colour, as it was so fashionable at the time.

Emerald green was also a popular artist-quality pigment used by Van Gogh, Cezanne and other Post-Impressionists around the late 1800s. After its toxic effects were discovered, the pigment was no longer used for making textiles and furnishings. However, it continued to be used as rat poison.

Learn more about dangerous fashion from this book: Matthews David, Alison. *Fashion Victims: The Dangers of Dress Past and Present*. London: Bloomsbury Publishing USA, 2017

Figure 3.57. Old tin of Paris Green paint. Image attribution: Chris goulet at English Wikipedia, Paris Green (Schweinfurter Grün), CC BY-SA 3.0. Select image to enlarge.




**White Lead (or lead white)**

This was a common pigment made from lead carbonate, and its use dates back at least as far as 300 BCE. It was created using what was called “the Dutch method”, where lead was exposed to vinegar for long periods of time, which would corrode the lead and turn it white (the smell was supposed to be terrible). This white substance would then be scraped off and ground into a powder. It was highly toxic because of the lead content.

White lead (Figure 3.58) was popular as an artist’s oil paint due to its opacity and smooth texture. It was also used in cosmetics as a face paint or powder. Both uses were dangerous, causing health issues and death for those who had ongoing contact with the pigment. Perhaps because of its toxicity, it was used in the 18th century to paint wooden ship hulls and floors because it helped to prevent infestation by shipworm – a pest that would eat the ship’s timber. Lead white pigment is now banned in most countries, although an artist’s material known as ***Flake white*** or ***Cremnitz white*** does still exist and can be purchased in some formats. Some artists still prefer lead white to zinc white or titanium white because it’s more translucent, not as flat, and mixes well with other coloured pigments. A lead-free flake white is now also available that contains a mixture of other kinds of white pigments.

Figure 3.58. Old tin of Dutch Boy white lead paint. Image attribution: Thester11, LeadPaint1, CC BY 3.0. Select image to enlarge



**Vermilion/cinnabar**

Also known as Sindoor, vermilion is a bright red pigment that is highly toxic because of its mercury content (mercury sulphide is its main element). Vermilion made from cinnabar was used across many cultures since prehistoric times in paintings and objects. It is well known as ***Chinese Red*** for the red lacquer paint applied to furniture and objects. It was a very popular artist’s pigment during the Middle Ages and Renaissance, although it was very expensive. It has also been used in cosmetics since ancient times, across Asia, Europe and the Middle East in products like lipstick and cheek rouge because of its vibrant red colour. Mining, working with, and wearing the pigment caused mercury poisoning.

As an artist’s pigment, it wasn’t very lightfast, so was prone to fading over time (see Figure 3.59). Today, it has been replaced by Cadmium red as a safer and more stable option.

Read this article on How Stuff Works to learn more about cinnabar toxicity.

Figure 3.59. Painting by Joshua Reynolds – the vermilion cloak has faded from a vibrant red to a pale pink over time. Image attribution: Joshua Reynolds artist QS:P170,Q194402, Charles Coote, 1st Earl of Bellamont, marked as public domain, more details on Wikimedia Commons. Select image to enlarge.



**Cochineal**

This is a scarlet-red dye or pigment made from cochineal beetles (Figure 3.60). While not toxic or unethically produced like the other pigments listed here (unless you are vegan), the failed attempt to create a cochineal industry in Australia in the late 1700s led to the imported prickly pear plant *Opuntia* running wild and becoming a restricted and prohibited weed (it was brought to Australia as a food source for the beetles).

Eventually, in the early 1900s, another insect, the *cactoblastis* moth, was brought to Australia as part of a prickly pear reduction program. These moth larvae were very successful in destroying the plant, which had an enormous impact on the land and enabled settlement of areas previously infested with prickly pear. It is still regarded as one of the most successful weed eradication programs using biological means instead of harmful chemicals. Learn more about the prickly pear story here .

There is some controversy over the use of cochineal as a food colouring, which, if not specifically disclosed, is a problem for vegans, vegetarians, Muslims and other people who choose not to eat insect-based products.

Figure 3.60. Cochineal pigment production. Image attribution: Thelmadatter, GutierrezWorkshopTeotitlan055, CC BY-SA 4.0. Select image to enlarge.



**Indigo**

Indigo is not a toxic dye, but indigo plantations have an unethical historical association with the African slave trade in North America and elsewhere around the world. Many people were forced to work in indigo plantations under terrible conditions with cruel mistreatment by plantation owners and managers. Other crops like cotton, tobacco, sugar and coffee have similar histories.

The development of synthetic indigo meant the end of indigo plantations. However, there is a return to more sustainable and environmentally friendly methods of dye production that don't use petrochemicals. Natural indigo (Figure 3.61) may yet have a resurgence in popularity, although with more ethical and sustainable production processes.

Learn more about the history of indigo in this article: The Dark History of Indigo, Slavery's Other Cash Crop by Jesslyn Shields, HowStuffWorks.com, Feb 7, 2020

Figure 3.61. Indigo plant *(Indigofera tinctoria)* Image attribution: Kurt Stüber, Indigofera tinctoria1, CC BY-SA 3.0. Select image to enlarge.



**Luminous radium paint**

Known as the **Radium Girls,** many girls and women in the early 20th century were poisoned by working with luminous paint that contained radium (which glowed in the dark), to create watch, clock and instrumentation dials (Figure 3.62). The women engaged in this factory work were encouraged to lick the tips of their brushes to create a fine point, thereby ingesting the radium, which caused terrible health conditions, including dental problems, fertility problems, necrosis of the jaw, anaemia and cancer.

Figure 3.62. Photograph of a factory scene from 1922, United States Radium Corporation showing women and girls using radium paint with no protection or warnings. Image attribution: Unknown author, All women or girls using radium paint with no protection or warnings in 1922, from- USRadiumGirls-Argonne1,ca1922-23-150dpi (cropped), marked as public domain, more details on Wikimedia Commons. Select image to enlarge.

## Further reading

You can find more information about the topics on this page by reading:

Coles, David, and Adrian Lander. *Chromatopia : an Illustrated History of Colour*. Port Melbourne, Vic: Thames & Hudson, 2018,

or visit this website: Pigments Through the Ages.

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# 3.6: Colour Wheels and Relationships

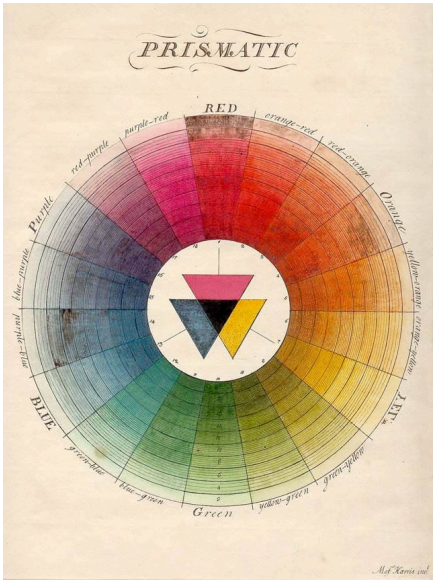



Figure 3.63 Harris' RYB Colour Wheel. Image attribution: Moses Harris, The Natural System of Colours and Ignaz Schiffermüller, Versuch eines Farbensystems (Vienna, 1772), plate I, Moses Harris, The Natural System of Colours, marked as public domain, more details on Wikimedia Commons

Colour wheels (Figure 3.63) have been used for hundreds of years as a method of working with colour – to understand mixing colour, creating colour palettes and relationships, and selecting colour in software applications.

Many early colour wheels used the RYB (Red, Yellow, Blue) primaries alongside secondary and tertiary colours in a wheel, but today, with digital technologies influencing how we create works that use colour, it is accepted that the additive colour primaries (RGB) (or CMY for subtractive colour) are the standard used in software applications as screen-based media work with additive colour (pixels are made of light).

## Interactive colour wheel and colour relationships

### Instructions for using this colour wheel (Figure 3.64)

1. Choose a colour **scheme** from the drop-down list and drag the circles around the colour wheel to create your own palette of colour relationships.
2. You can change the **saturation** or intensity of a **hue** by moving the circles closer to or further from the centre of the circle.
3. You can also change the **shade** of the colour with the sliders at the bottom of the wheel to create a darker **value** of the same hue.
4. Colours are shown as **Hexadecimal** values in this wheel. You can use these values in most image editing software applications.

### Colour relationships and schemes

The interactive colour wheel in Figure 3.64 has a selection of colour schemes that you can use to create harmonious and vibrant colour relationships and palettes.

Here are definitions of these schemes:



**Monochrome**

A monochromatic colour scheme contains a single colour **hue** with varying **shades** and **tints**, which are darker and lighter colours of the same hue (see **Properties of colour** in this resource for more about shades, tints and tones)

Figure 3.65. Colour wheel diagram showing monochrome colours. Image attribution: *see attribution at the bottom of this page*.



**Analogous**

An analogous colour scheme contains one main **hue (colour)** with the colours on either side of it on the colour wheel. For a five-colour scheme, it may also contain the two adjacent colours on the colour wheel.

Colour **Bias** is also related to analogous colour. This term refers to the way that a colour may be ***biased*** towards another adjacent colour on the colour wheel – for example, you may have a red hue that has an orange colour bias or a purple colour bias and is not a pure "red" colour. In fact, many pigments we think of as primary or "pure" colours actually have a colour bias and are not pure spectrum colours.

Figure 3.66. Colour wheel diagram showing analogous colour hues. Image attribution: *see attribution at the bottom of this page*.



**Complementary**

A complementary colour scheme contains the two colour **hues** directly opposite each other on the colour wheel.

Figure 3.67. Colour wheel diagram showing complementary colour hues. Image attribution: *see attribution at the bottom of this page*.



**Split-complementary**

A split-complementary scheme includes one dominant colour **hue** and two hues on either side of the dominant colour's complementary hue.

Figure 3.68. Colour wheel diagram showing split-complementary colour hues. Image attribution: *see attribution at the bottom of this page*



**Triadic**

A triadic colour scheme has three colour **hues** that are equally spaced around the colour wheel, forming a triangle shape.

Figure 3.69. Colour wheel diagram showing triadic colour hues. Image attribution: *see attribution at the bottom of this page.*



**Tetradic**

A tetradic colour scheme has four hues that form a rectangle within the colour wheel. There is also a **quadratic** scheme where the four hues form a square that is more evenly spaced than the tetradic rectangle, which could be any rectangular shape.

Figure 3.70. Colour wheel diagram showing tetradic colour hues. Image attribution: *see attribution at the bottom of this page.*

See Colour trends and palettes in this resource for a selection of colour palette generators.

## The Dimensions of Colour Today: ICD 2022 (David Briggs)

This video is a recording of a talk by David Briggs, who is an Australian authority on colour theory. He bases the talk on content from his website *The Dimensions of Colour* , highlighting some developments in how we understand colour and colour relationships. He gives an overview of the alternative frameworks available today for visualising colour relationships. It is an academic video, but the imagery and diagrams make these complex concepts easier to understand. The YouTube page also contains links to all the resources and tools he references in the video. (34 minutes)

YouTube Video

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this YouTube Video online

Media attribution: ICD 2022: The Dimensions of Colour Today (David Briggs), Colour Society of Australia NSW Division on YouTube

Image attributions for this page: Colour wheel images on this page (figures 3.65 to 3.70) by RMIT, CC BY-NC 4.0.

# Properties of colours

This page contains simple definitions of the basic properties or attributes of colours of objects and colours of light, which are

useful to understand if you are working with colour applications and developing colour relationships or palettes. For further information, refer to *The Elements of Colour* by DJC Briggs[1], which provides a detailed illustrated account of these attributes including their scientific definitions.

**Hue**

Hue is a term that we use to classify colours of objects and colours of light into families that vary in other colour properties. The hue of any colour is the most similar pure colour around the colour wheel, such as red, or magenta, or greenish yellow. ("Pure" in this context means lacking perceived white, black, or grey content, as described in Tints, Shades and Tones below). So, for example, we might say that the hue of a brown wooden table is orange or yellow orange.



Figure 3.71. Hue colour wheel by RMIT, CC BY-NC 4.0

For a light, Hue is our perception of the dominant part or parts of the visible spectrum. For an object, Hue is our perception of the dominant *spectral reflectance* of the object.
(For "spectral reflectance", see Why are things different colours?).

When we describe a light or an object as being "coloured", we generally mean that it exhibits hue, and yet we may include black, white and grey, which lack hue, as "colours" in a practical sense – for example, when referring to paints or fabrics. Black, white, and grey are classified scientifically as "achromatic colours" [2], as opposed to "chromatic colours", which exhibit hue.

**Chroma and Saturation**

Many people use Chroma and Saturation to mean the same thing, but according to the CIE *International Lighting Vocabulary* [3] they have different definitions that correspond to different aspects of colour intensity.



Figure 3.72. Saturation colour wheel by RMIT, CC BY-NC 4.0. The colours decrease in both Saturation and Chroma towards the centre of the circle. (Compare Figure 3.75 below, the shades colour wheel, where the colours decrease in Chroma towards the centre but stay high in Saturation).

Chroma applies specifically to colours perceived as belonging to objects, and is the absolute intensity of an object's colour, that is, the amount of difference from a grey of the same Value. In Figure 3.A, Chroma is represented by increasing distance to the right, beginning at zero for black, white and grey. In a colour wheel like Figure 3.72 the relatively "pure" colours on the circumference have the highest Chroma for their hue. However, the possible maximum Chroma varies greatly for different paints, inks and digital colours, and is not the same for different hues, and so distance from the centre in a symmetrical colour wheel like this normally shows relative rather than absolute Chroma.

Saturation on the other hand applies both to colours of light and colours of objects and is the intensity of colour (called Colourfulness; see below) of a light *relative to its Brightness*, or the intensity of colour (Chroma) of an object *relative to its Value*. An achromatic light or object exhibits zero saturation, a light exhibiting high saturation is perceived to consist of a relatively high proportion of coloured light to white light, and an object exhibiting high saturation is perceived to reflect/ transmit light of this character to the eye. The colours on the circumference of Figure 3.72 exhibit high Saturation (as well as Chroma), but so do darker colours that are high in Chroma for their Value (seen in Figure 3.75 below). "For an object to have high chroma it must reflect/ transmit saturated light in relatively large amounts." [4].

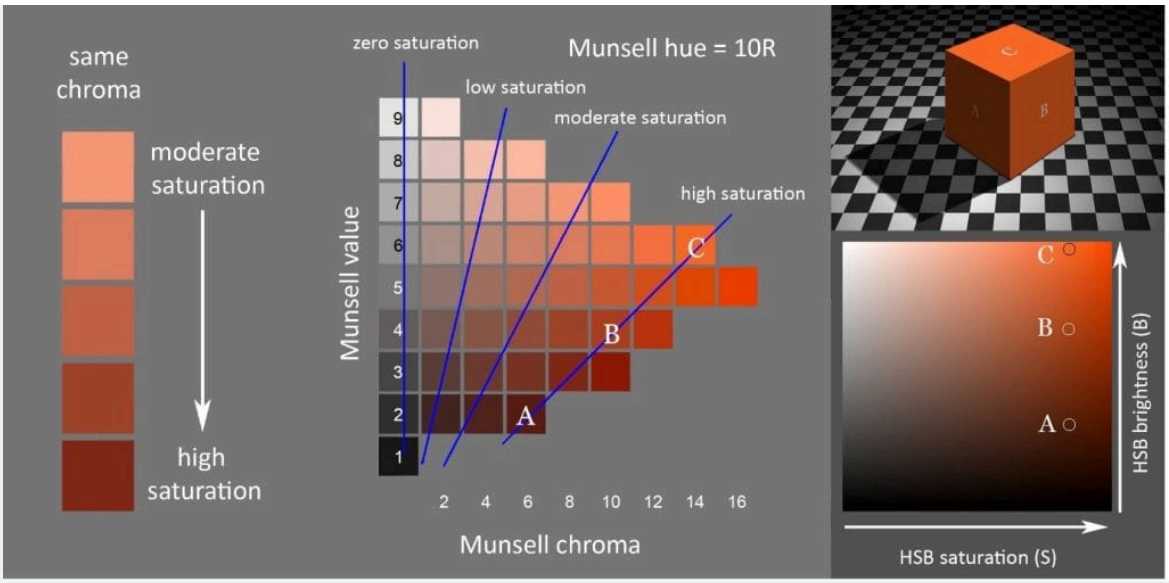



Figure 3.72a. Left swatches in a column from a Munsell hue page exhibit uniform chroma but increasing Saturation going down the column. Middle: swatches exhibiting uniform Saturation, including those similar to image areas A, B and C in the image of the cube to the right, are arranged along lines that radiate from near (actually one value step below) zero on the value scale. Right: areas A to C are depicted using digital colours of uniform hue angle H and "Saturation" S in the colour space HSB. Image provided courtesy of D.J.C Briggs, 2017 CC BY-NC 4.0.

**Value/lightness and value/greyscale**

Value, greyscale value and lightness are alternative names for the same property of colour. The Value of a colour is the most similar or least contrasting grey on a scale between black and white (Figure 3.73). In Figure 3.A, Value is represented by horizontal level within the diagram.

Like Chroma, Value applies specifically to colours perceived as belonging to objects. Value is our perception of the proportion of the light falling on an object that the object reflects. For example, a dark green object reflects less light and therefore has a lower value than a pale green object.

In a painting or a photograph, Value helps us greatly to identify objects as three-dimensional by representing the variations in light and shade on objects.

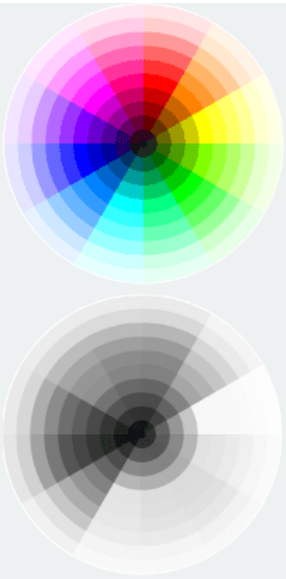


Figure 3.73. Value colour wheel and same wheel converted to greyscale with the same values, by RMIT, CC BY-NC 4.0.

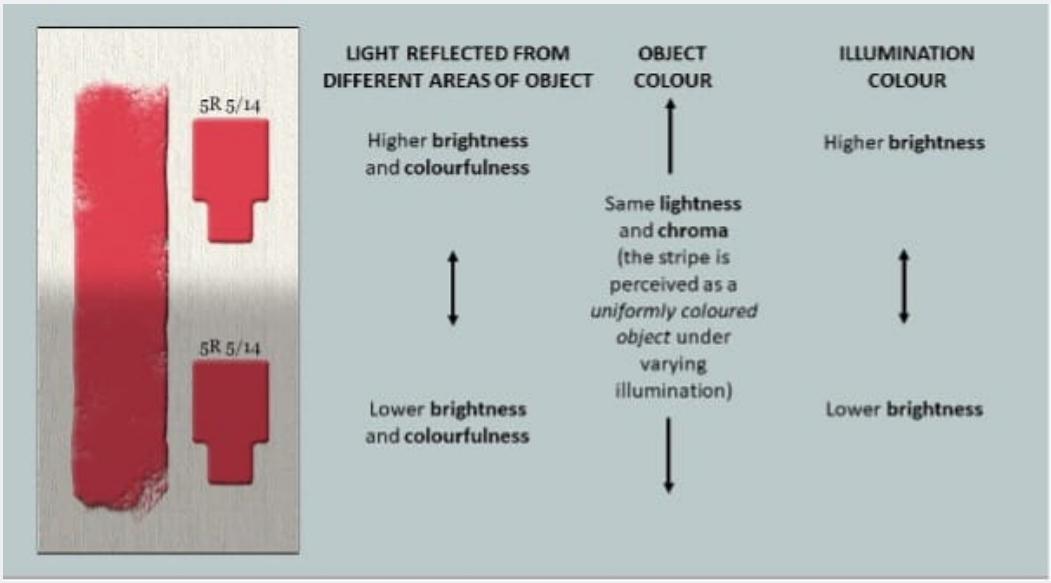



Figure 3.73a Digital painting of a stripe of red paint passing between different intensities of the same illumination, showing relationship of attributes of the colour perceived as belonging to the red stripe, and attributes of the colours of the light reaching our eyes from different areas of the stripe and of the light perceived to be falling on the stripe (the illumination)[5], from David Briggs' presentation "Colours of objects and Colours of Light". Image provided courtesy of D.J.C. Briggs, 2017 CC BY-NC 4.0.

**Brightness and Colourfulness**

Brightness and Colourfulness are properties of colours we perceive as belonging to light, including the light reflected, transmitted or emitted to our eyes by objects, and the light falling on objects (the illumination). Brightness is our perception of the amount of light, and colourfulness is our perception of its intensity of colour. In contrast to colours of objects, which we saw can be described in terms of Hue, Value and Chroma (Chroma can often be called "Saturation"), colours of light can be described in terms of Hue, Brightness, and either Saturation in the scientific sense described above or Colourfulness.

A uniform object under varying intensities of the same illumination will normally be perceived as having a uniform colour belonging to it (uniform Hue, Value and Chroma), while the light reaching our eyes from different areas of the object varies in Brightness and Colourfulness (Figure 3.73a). These variations in Brightness and Colourfulness are perceived as being imposed by the illumination rather than as belonging to the object itself. Illumination can also be perceived to exhibit Hue, Brightness and Colourfulness/Saturation, though the illumination in Figure 3.73a is perceived to be achromatic (white), varying only in Brightness.

**Blackness, Chromaticness and Brilliance**

A different way to classify colours of objects, besides Hue, Value and Chroma, is according to their degree of resemblance to a pure black, a pure white and a pure colour. This is the basis of the Scandinavian *Natural Colour System* (NCS), in which these resemblances are taken to add up to 100 and plotted on a triangular diagram for each hue (Figure 3.Z, left), and colours of objects are specified by their resemblances to pure black and pure colour, called Blackness and Chromaticness respectively.

Colours of zero blackness, between a perceptually pure colour and white, lie near the approximate upper limit of commonly encountered colours of objects. As swatches increase in brightness beyond this limit, they take on the appearance of physical fluorescence, called Fluorence, and ultimately appear as self-luminous Illuminant colours. The scale of colour appearance from black through decreasing Blackness to zero Blackness, followed by Fluorence and then Luminosity is called “Brilliance” [6].

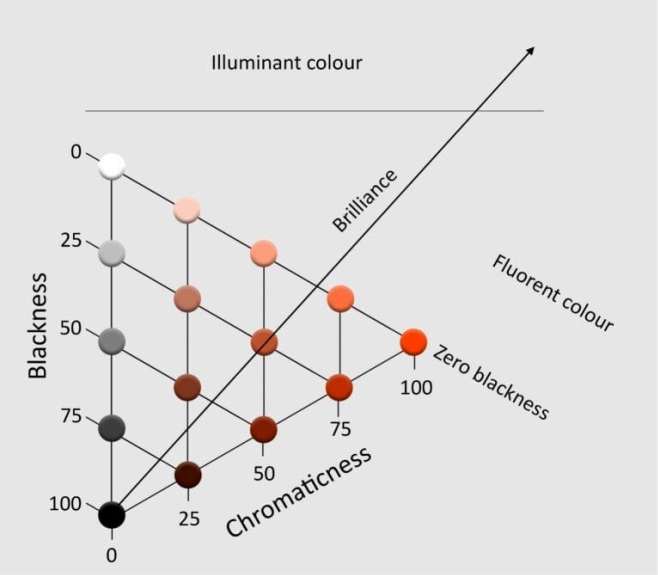



Figure 3.73b Diagrammatic subdivision of a hue page according to Blackness and Chromaticness (degree of resemblance to pure black and to pure chromatic colour respectively), showing relationship to Fluorent and Illuminant colours, and the scale of Brilliance [7]. Image provided courtesy of D.J.C. Briggs, 2017 CC BY-NC 4.0.

**Tint**

In traditional colour theory, the term “Tint” may be used for colours between a pure colour or “Hue” and white, or for physical mixtures of a coloured paint and white paint. In the first sense a Tint has the same hue as the pure colour and is between that colour and white in Value and Chroma. In the second sense, Tints may shift in Hue and pass through higher Chromas than the coloured paint.



Figure 3.74. Tints colour wheel by RMIT, CC BY-NC 4.0.

**Shade**

In traditional colour theory, the term “Shade” may be used for colours between a pure colour or “Hue” and black, or for physical mixtures of a coloured paint and black paint. In the first sense a Shade has the same Hue as the pure colour and is between that colour and black in Value and Chroma. In the second sense, Shades may shift in Hue compared to the coloured paint.



Figure 3.75. Shades colour wheel by RMIT, CC BY-NC 4.0.

**Tone**

In traditional colour theory, the term “Tone” may be used for colours between a pure colour or “Hue” and grey, or for physical mixtures of a coloured paint and grey paint. In the first sense a Tone has the same Hue as the pure colour and is between that colour and black in Chroma. In the second sense, Shades may shift in Hue compared to the coloured paint. The term “Tone” is also used in some countries as an alternative name for Value/Lightness.



Figure 3.76. Tones colour wheel by RMIT, CC BY-NC 4.0.


1. 1. Briggs, D.J.C., 2023. “The Elements of Colour”, Part One, https://aic-color.org/resources/Documents/jaic_v33_06.pdf and Part Two, https://aic-color.org/resources/Documents/jaic_v33_07.pdf. For additional illustrations and animations please see the related video presentations “The Elements of Colour”, https://www.youtube.com/watch?v=AtrRpGb-7FU, and “Colours of Objects and Colours of Light”, https://www.youtube.com/watch?v=ii9dWIG9nOY. accessed 03/01/2023
2. CIE, 2022, achromatic colour definition - also known as "perceived colour devoid of hue", https://cie.co.at/eilvterm/17-22-049
3. CIE 2023, *International Lighting Vocabulary* http://www.cie.co.at/ accessed 05/11/2023
4. Briggs, D.J.C., 2018. “The Difference Between Chroma and Saturation", Munsell Color, https://munsell.com/color-blog/difference-chroma-saturation/ , accessed 03/01/2023
5. 4. Briggs, D.J.C., 2017. “The Dimensions of Colour: Brightness and Colourfulness” http://www.huevaluechroma.com/016.php
6. Op. Cit. Briggs 2023, p.110
7. Op. Cit. Briggs 2023, Part Two, Figure 10


## Test yourself: colour wheels and relationships

### A multiple choice quiz to test your understanding of colour wheels and relationships

#### (5 minutes or less)

Interactive Content

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this Interactive Content online

## Colour properties: tints, shades and tones – learning activity

This interactive learning activity is a simple drag-and-drop exercise that covers what you have learned in this chapter.

Drag the colour swatches onto the boxes in the correct order for tints, shades and tones, and check to see if your guesses are correct.

## Colour properties: light to dark – learning activity

This interactive learning activity is a simple drag-and-drop exercise that covers what you have learned in this chapter.

Drag the colour swatches onto the boxes in the correct order and check to see if your guess is correct.

## Colour properties: monochrome (greyscale) – learning activity

This interactive learning activity is a simple drag-and-drop exercise that covers what you have learned in this chapter.

Drag the colour swatches onto the boxes in the correct order for greyscale from light to dark, and check to see if your guess is correct.

Interactive Content

*This interactive element is not available in this format. Visit the link or scan the QR code to access it online.*

View this Interactive Content online

## Colour relationships: bias colour scale – learning activity

This interactive learning activity is a simple drag-and-drop exercise that covers what you have learned in this chapter.

Drag the colour swatches onto the boxes in the correct order for the colour bias scale from teal to yellow-green, and check to see if your guess is correct.

## Colour charts – Pantone and Munsell systems

The colour systems currently used in creative and design industries for selecting and matching colours with a high degree of accuracy are produced by **Pantone** and **Munsell.**

Pantone colour is a dual system that displays charts or “guides” of proprietary colours that are described with different

information, such as CMYK values and Pantone spot colour identifying codes.

The Munsell colour system is different to Pantone – it is a way of classifying visible colours with a number system. A colour could be classified in both the Munsell system and in a Pantone colour guide.

This resource cannot display more than a few selected images, as both of these systems are under the copyright of their companies. Their websites and related links provided on this page, however, do have detailed information about how these systems work, and how you can use them in your creative practice.

**Pantone colour**

The image in Figure 3.77 displays a sample taken from a Pantone colour guide. The whole digital chart would be too large to display here. You can find more complete examples on the Pantone website.

This online resource also has a web version of the Pantone PSM colour chart . Keep in mind that any digital Pantone chart will not necessarily show the exact colour you will see when printed. The reason hard-copy swatch books are used in the design industry is that they show the exact physical colour of a Pantone pigment. It is also advised that swatch books are updated regularly, as some pigments may fade or change over time and not show accurate colours.




Figure 3.77. Pantone colour guide, via Wikimedia Commons, licensed under CC BY-SA 3.0.

**Munsell colour system**

The image in Figure 3.78 is a sample of the twenty basic hues in the Munsell colour system. Each of these **hues** has a colour chart showing the different **value** (lightness or darkness), **chroma** (saturation or brilliance) and relationships between the colours. Learn more about the Munsell colour system from the ***Munsell Color* website**

Andrew Werth has created a ***Virtual Munsell Colour Wheel*** that allows you to browse Munsell colour notations – a useful tool for designers. Each colour in this tool has the Munsell colour notation, plus RGB and Hex values.

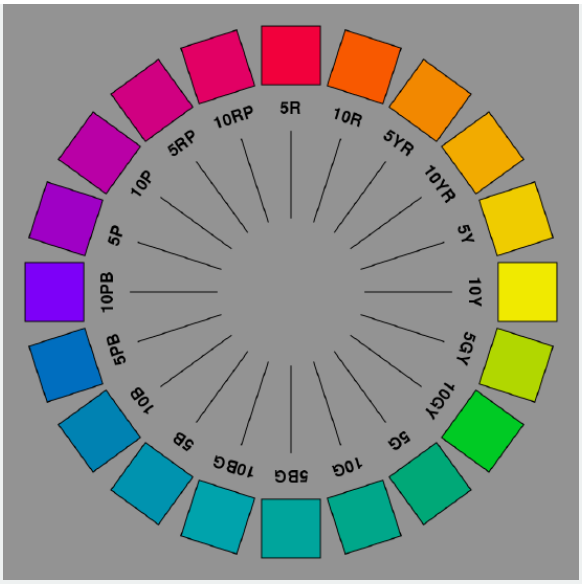



Figure 3.78. Twenty hues of the Munsell colour system at maximum chroma in the sRGB gamut. Image attribution: Thenoizz, MunsellColorWheel, CC BY 3.0

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# 3.7: Color Terms

## Introduction

The following terms will be used throughout the course in your readings and assignments.

- **Achromatic Grays**: Grays without hue or saturation, only value. Achromatic means “without color”.
- **Additive Color**: Color seen as light. Additive primaries are red, green, and blue. When they are combined the result is white light.
- **Analogous**: Hues are next to each other on the spectrum and the color wheel.
- **Bridge Tones**: Tones that provide a transition between two different colors. This is achieved by gradually mixing the second color with the first.
- **Color Structure**: Three factors influence the appearance of color: hue, value, and saturation.
- **Chromatic Darks**: Dark chromatic grays that have discernible temperature and hue.
- **Chromatic Grays**: Chromatic grays have relatively low saturation, but still have discernible hue and temperature.
- **Color Harmony**: The character of the interrelations in groups of colors. Harmonious colors are highly unified. Inharmonious or discordant colors are in disagreement with each other.
- **Color Interaction**: Quality of a color depends upon its context. An identical color can appear different from a different context to another.
- **Color Temperature**: Division of warm and cool zones on the color wheel.
  - **Warm colors**: Red-violet, red, orange, yellow, yellow-green.
  - **Cool colors**: Violet, blue-violet, blue, blue-green, green.
- **Color Wheel**: Circular graphic display of the spectrum, usually in 12 major hues that include primary, secondary and tertiary colors.
- **CMYK**: Colors used in four color printing: cyan, magenta, yellow and black.
- **Complementary Hues**: Complements are any two hues that are directly opposite each other on a color wheel. When complements are mixed, the resulting color is darker and duller than both of the two parent colors.
- **Earth Tone Primary**: A triad of earth tones: burnt sienna, yellow ochre, and Payne’s gray (a blue gray mixture of ultramarine blue & black).
- **Gamut**: A range of hues available to a particular color mode, such as the visible spectrum, RGB (computer screen) and CMYK (four color printing).
- **Grayscale**: Representation of the value continuum broken down into distinct and evenly progressing achromatic grays.
- **High Key**: Values in a color image are predominantly light.
- **Hue**: One of three structural factors of color (along with value and saturation). The name given to a color to describe its location on the color spectrum.
- **Keyed**: Color groupings are keyed when they are brought together in either hue, value, saturation, or combinations thereof.
- **Low Key**: Values are “keyed” predominantly dark in an image.
- **Luminosity**: Light reflected from a surface. The lighter the color the more luminous it is.
- **Median Transparency**: An illusion of transparency created by overlapping two colors diverse in value. The overlapping area of the two colors appears to be an equal blend of the two adjacent colors.
- **Monochromatic**: Color schemes that are limited to one hue and variations thereof. There may a broad range of value and saturation levels.
- **Muted Colors**: Muted colors are softer than prismatic colors, but still retain a sense of hue identity.
- **Optical mixing**: Small color fragments next to each other are fused into seamless transitions by the eye. Used in tapestry, mosaic, four color printing and Pointillism (see artist Georges Seurat).
- **Primary colors**: Red, yellow, blue - cannot be obtained by mixing.
- **Primary triad**: Primary red, yellow and blue triangle on the color wheel. In theory, all colors can be mixed from the three primary colors.
- **RGB**: Red, green, blue. Colors used in additive or lighting color.
- **Saturation**: The relative purity of hue in a color. Highly saturated colors are vivid and rich in hue. Low saturation colors are dull and show a weak hue presence. Three levels of saturation: prismatic color, muted color and chromatic gray.
- **Secondary (triad) colors**: Green, orange and violet. Each of these colors are created by mixing two primary colors.
- **Shade**: The result of mixing any color with black.
- **Simultaneous Contrast**: Simultaneous contrast is the optical effect that two neighboring colors have upon each other as their afterimages interact along a shared border. This is most evident when highly saturated exact complements are placed

side by side.
- **Spectrum**: A phenomenon of light that can be seen in a rainbow or through a prism. The spectrum contains the full range of hues present in sunlight.
- **Subtractive color**: Color from reflected light, rather than direct light. Subtractive color primaries are red, yellow and blue which, produce a dark dull tone when intermixed.
- **Tertiary colors**: Also called “intermediate colors are yellow-orange, red-orange, blue-green, yellow-green, blue-violet and red-violet. They are produced by mixing one primary color with one secondary color.
- **Tint**: A tint results when any color is mixed with white.
- **Tones**: A generic term that refers to any color but a prismatic color. All muted colors and chromatic grays are tones, as are all tints and shades.
- **Value**: The relative quality of lightness or darkness in a color. It is the only structural factor visible in achromatic images, as in black and white photography. Value means luminosity.

## Works Cited

Hornung, David. *Color: A Workshop for Artists and Designers*. 2nd ed. London: Laurence King, 2012.

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