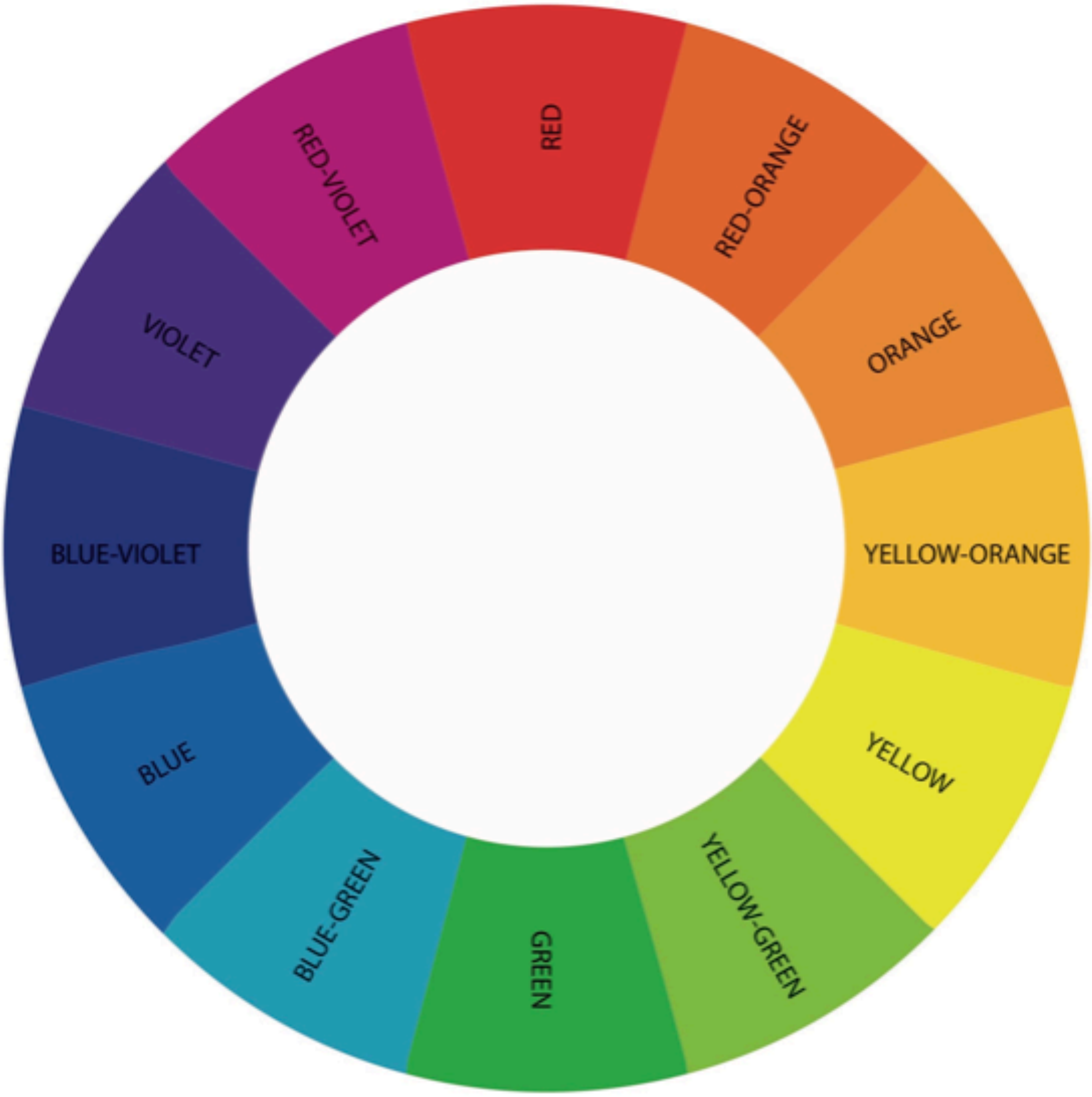
COLOUR THEORY AND PRACTICE

A preliminary text compiled by Allen Fisher



Colour Theory and Practice.

I first issued this pamphlet in 1994 as part of a college curriculum. Some elements have been revised for this edition.

CONTENTS

1. LIGHT

One of the problems in dealing with ideas about light has to do with the vocabulary we use to speak about it. From ancient times light has been variously spoken of as travelling in rays, waves and particles. More recently the way in which light is described couples the words wave and particle or wave and packet. More recently still the term *quanta* has been in use. The problem arises because of the unequal experiences between what we see with our eyes, what machines provide as information and analysis of effects produced by light.

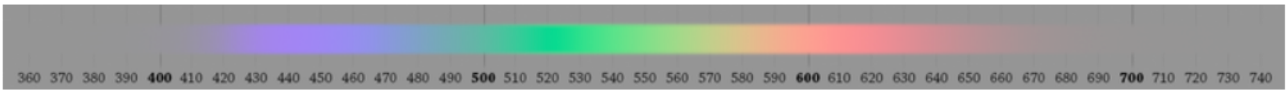
These days most artists and scientists agree that light is electro-magnetic energy. Sometimes when it is interfered with, such as by an opaque sheet with slits in it, light behaves as if it were travelling in waves. Sometimes when it is used to charge solar cells in batteries it behaves as if it were photons or particles transforming matter.

To describe light scientists measure its wavelength and the frequency of the oscillation. The ratios of wavelength, frequency and the velocity of light are constant. This means that if the velocity of light is slowed down by a transparent substance like water or glass the wavelength or the frequency also changes. These facts are important for the understanding of colour.

The frequency of oscillation of this quanta of electromagnetic energy that we call light determines our perception of different colours, or more technically, what are called **hues.** In 1929 spectrophotometers produced graphs giving exact measurements of each colour. The unit of measurement of light is the Nanometre (nm) (which means meter to the power of minus nine). Light visible to human sight is in the range from 380 nm to 760 nm. This is often presented as a **spectrum** from the shortest wavelength we call violet to indigo to blue and then to green to yellow to orange through to the longest wavelength we call red.

The electromagnetic visible spectrum can be illustrated diagrammatically using the following values:.

VIOLET 390 INDIGO 430 BLUE 460 GREEN 500 YELLOW 570 ORANGE 610 RED 700



2. **AIR, SKY AND WATER**

In its ideal and complete state light is **white** but when light travels through a medium, like glass, water or oil paint, changes occur. The velocity slows down, the light becomes refracted, some of the light is absorbed and some of it is diffracted. This helps us understand why the sky is blue, or sometimes red, why the water is blue and sometimes not.

When light passes through a transparent medium such as air or water one of the processes it undergoes is know as **absorption.** This means that the light with the longest wavelengths (which also means the lowest energy) like red are absorbed more strongly than those of higher energy (the short wavelengths) like blue. The more this process occurs the bluer the visible light appears. Light passing through the atmosphere of the Earth often makes the sky appear blue.
In addition to this, as light passes through the atmosphere the shortest wavelengths are scattered as they strike particles of dust, water, air molecules like carbon dioxide, oxygen, ozone and nitrogen, and trace elements causing the higher energy wavelengths (like blue) to reach the ground. This process is called **diffraction** and it makes the sky appear bluer.

Red skies occur because of a number of factors. The common red effect at sunset is due to a highlighting of the long red wavelengths which appear before the shorter blue in the sky.

Water not only acts as a transparent medium for the absorption and diffraction of light, it also reflects light. Because of the higher energy of blue wavelengths it is blue that is more readily reflected. The blue in the Chatsworth Ponds is a combination of the reflected blue sky and the absorbed red wavelengths.

In 1704 Sir Isaac Newton used a transparent prism in a darkened room to refract white light coming through a gap in the window into a spectrum of visible colours.

This spectrum of seven colours, seen in many rainbows or in soap bubbles under strong light, became the standard for more than a hundred years. In 1880 Joseph Lovibond invented colorimetry (colour measurement), which eventually led to the printers use of tints of yellow, magenta and cyan. More recent techniques have expanded that standard range. The Lovibond Tintometer used permutations of nearly 9 million filters.

3. EYESIGHT

When your eyes are closed you may experience a dark noise. It is not a perfect dark but a darkness full of sensations produced by thermal excitation of the chemistry in the retina of the eye. Perhaps you imagine colours, perhaps there is a minute leakage of light causing a scintillation effect, darts of light specks, in your darkness. When you open your eyes light enters that darkness and, in most humans, colour is perceived.

Colour is the electromagnetic energy of light transformed by the eye into electrochemical information and nerve impulses. This transformation process can be summarised. A description of perception would take a lifetime. Light enters the eye through the **cornea** and passes through a **lens** where it is directed by processes of refraction and reflection to the **retina**. In humans the retina carries photoreceptors based on rhodopsin molecules embedded in disk-shaped membranes with axes parallel to the incoming light. The retina is a layer of millions of rhodopsin-receptor cells, they are of two types:

i. **Rod Cells**

   These cells are specialised for dim light and used to interpret tonal values.

ii. **Cone Cells**

   These are specialised to function in bright light. At the back of the retina is a black pigment layer which prevents the escape of light.

Human vision, as already indicated, spans a range from about 450 nm for violet to about 800 nm for red light (it is sharpest between 500 and 600 nm). In humans colour vision is based on three pigments, which have absorption spectra centred on 420 nm (violet), 534 nm, (green) and 564 nm (yellow/green). (The latter is often called red because when it is operated without the other two pigments it produces a red sensation). The sensations of hue are based on **patterns of stimulation** across the receptor cells. The trichromatic (three-colour) information from these cells passes down the **optical nerve** to the brain where a further analysis occurs in an identified specialised region and where **consciousness**, and thus perception takes place.

The colours we perceive rely on the overlapping responses of the receptors. The colours perceived at one place in an image depend not only on the cone cell responses there but also on surrounding cone triplets in the eyes. The colours we see at one time also depend on those we saw moments before: the cones continuously adapt to changes in the prevailing light intensity and spectral composition, shifting both their sensitivity and set-point of operation. The cone responses code is, in this sense inefficient, because the range of quanta to which the distinct cone types respond to overlap greatly. The brain has evolved a second-stage mechanism that transforms the cone triplets into a more reliable and discriminatory code. In the four-dimensional spacetime spanned by all possible cone triplets, this transformation amounts to a rotation of the co-ordinate axes defined by the cone sensitivities. The brain carries out **a series of comparisons of cone responses against each other.**

4. ART AND DESIGN

The discussion of perception's complexity leads directly to the relation between trichromatic analysis in the Eye-Brain process and the recognition that colour is highly relative to its surroundings. Imaging sensitivity depends on the contrast of objects and their background, known as figure and ground. For an object to be detected by human eyesight it must differ in radiance from the background radiance in at least one range of quanta. Colour has three independent dimensions that contribute to this "detection":

i. **Hue** – dominant wavelength such as green, red, etc.

ii. **Saturation** – relative colourfulness or intensity

iii. **Brightness** – Lightness/darkness (amount of grey tone, value)

Artists and designers use a variety of methods to produce images with a view to making them detectable. A typical medium for the artist and designer is pigment. The pigment is mixed with adhesive and becomes paint, water colour or gouache, body colour or oil paint, acrylic paint or dye. Pigment is coloured by the light it reflects - pigments absorb certain types of light ad reflect others. The texture of the surface determines the coherency of the reflection. Light reflected from objects often has a characteristic colour when it reaches the eye. This is because a coloured object can completely absorb only quanta with exactly the right **energy levels** to fit its own atomic structure. An object that absorbs violet, blue and green light will not reflect these colours, but will reflect red, orange and yellow, which have lower energy levels; the object is thus seen as red. Disordered molecules in solid materials reflect quanta in regular patterns. Disordered molecules in liquids and sparse ones in gases can also interact with light that passes through them.

The production of colours by mixing dyes or pigments, or superimposing in transparent coloured filters is called subtractive mixing. The resultant colour is the result of the simultaneous or successive subtraction of various colours from the light passing through the combination. Yellow, cyan and magenta printing inks together absorb almost all the wavelengths of incident light. When superimposed on one another they produce a brownish black. The yellow absorbs blue and some violet light; the cyan absorbs red and some orange light and the magenta absorbs green and some yellow light.

When light beams of different colours are projected onto a white area, the light reflected is a mixture whose colour derives from adding together the colour beams. This is called **additive mixing.** Red, green and blue lights, projected at equal intensities, add together to produce 'white' light. This is the video-maker's palette. A further set of notes of contrast effects follows below.

5a. **COLOUR WHEELS**

The basic Colour Wheel uses what have been traditionally called Primary Colours. The Primary Colour pigments are **Red, Blue and Yellow.**
When two primaries are mixed together they produce a Secondary Colour. The Secondary Colours are **Purple, Green and Orange.**
The colour wheel may be used to conceptualise the complementary colours. Orange complements blue and is opposite blue on the wheel, but Complementary Colours must be of equal tonal values (grey scale) to be truly complementary.

5b. **BIAS WHEEL**

The Bias Wheel is a colour wheel that assists conceptualisation of bias among named colours and pigments. Human eyesight cannot fix a primary colour, but it can decide about biases. Each colour sensation has a bias towards one of its analogous colours. This can best be described through pigments.

RED PIGMENTS

i. **Alizarin Crimson** is a red with a bias towards blue. It is a lake, an organic product of coal tar called Anthracene. It was introduced in 1868 and is the only universally approved synthetic organic pigment. It is transparent and permanent.

ii. **Cadmium Red** is a red with a bias towards orange. It is a salt composed of Cadmium Sulphide and Cadmium Selenite. These days it also contains Barium Sulphate. It was first introduced in Germany in 1907. It is opaque and permanent.

YELLOW PIGMENTS

i. **Cadmium Yellow** is a yellow with a bias towards orange. It has the same composition as Cadmium Red but with a different chemical structure. It was commercially available in Germany in 1829 and in England in 1846. The salt was discovered in 1817.

ii. **Lemon Yellow** is a yellow with a bias towards green. It is Barium Chromate and sometimes called Barium Yellow. These days we buy a synthetic hue to replace Barium Chromate which is a poisonous salt.

BLUE PIGMENTS

i. **Ultramarine Blue** is a blue with a bias towards violet. Until the Nineteenth Century it was ground from Lapis Lazuli from Persia (Iran), Afghanistan, China and Chile. Since 1828 it has been manufactured from heating clay, soda, sulphur and coal. It is semi-transparent and permanent. Shops usually sell a synthetic version of the paint labelled 'Ultramarine Blue (Hue)'

ii. **Cerulean Blue** is a blue with a bias towards green. It is sometimes named CERULEUM meaning Sky Blue. Cerulean Blue is Cobaltous Stannate (a molecule of cobalt and tin oxides). It is quite opaque and permanent. It has been produced since 1805 and was introduced into England by George Rowney in 1870.

6. **TRADITIONAL CONTRAST EFFECTS**

Medieval illuminations, early Renaissance paintings, Tibetan tankas and Bangladesh rickshaws all use a **contrast of hues** combining red with yellow and blue with gold. The effect is heightened by tints and greys. The method is very close to that of **tonal contrast**, black against white, Prussian Blue against Sky Blue, and is akin to the idea of contrast by saturation in which brilliant colour is set against dull.

A method, very much favoured by those looking for psychological values in colour, is that of the **cold-warm contrast**. It was displayed by Goethe in his Colour Theory and continued at the Bauhaus by Kandinsky and Itten. By this method blue is cold and red is warm, just as ice and fire. Whilst Edvard Munch required green to signify jealousy, some German Expressionists extended symbolist ideas through Theosophy labelling blue spiritual and red directive.

The Nineteenth and early Twentieth Centuries also sew an increase in interest in the idea of **synaesthesia** in which the senses are intermixed and colour can evoke a smell or sound. Writers from Baudelaire, Rimbaud, Huysmans and Mallarmé to painters from Redon, Gauguin and Kandinsky and musicians like Scriabin, all experimented with ideas of synaesthesia.

A large group of contrast methods is encompassed by the use of **Complementary Colours.** A system was coded and considerably elaborated by Chevreul in 1839 and extended by the later work of Delacroix and the Pointillist techniques of Seurat and some of his peers. The system relies on the exactness, or the trial and error, of an idealised colour wheel in which the opposite segments are complements: violet opposite yellow; blue opposite orange; green opposite red. Mixing complementaries produces a neutral grey/black. Adjoining complementary colours is a method used to intensify colours producing in them a brilliance. **Simultaneous contrast** uses the complementary colour system. Physiological phenomena confirms that, for instance, staring at green and then closing the eyes produces its complement, red. Simultaneous colour contrast uses this phenomena so that a strong red produces a reddish grey in an adjoining dove grey. positioning and area.

Designers and artists have also recognised that colour has a range of affectivity in terms of positioning and area. Colour can be used to make an image appear larger or smaller, nearer or further away. Placing colour in constructive positions, using central colours in a scene or image from which to derive adjoining colour and opposing areas of different sizes produces a whole range of experiments promoted through the very different arts of Paul Cézanne, Josef Albers and Hans Hofmann.

7. **Selected Chronologue: 'A history of colour theory'**

1618 Francesco Grimaldi, light is a wave phenomena (disregarded until 19'" Century)

1651 Publication of Leonardo da Vinci's On Painting (Leonardo 1452-1519)(Light functions to reveal forms. Colour is subordinated to form and function only as the local colour of form.)

1704 Sir Isaac Newton. *OPTICS*

1801 Thomas Young, On the theory of light and colours 3 primary colours in human physiology

1807 Thomas Young uses word *and* concept ENERGY

1808 John Dalton's atomic theory

1810 Goethe's 'Colour theory'

1839 Eugene Chevreul's treatise on the simultaneous contrast of colours (first proposed in pamphlet 1828). Chevreul President of the Academy of Science in Paris and appointed Director of Dye Works at Gobelin.

1844 D. D. Jameson's 'Odour-music' instrument

1857 John Ruskin's *Elements of Drawing*

1860 Dalton's Atomic Theory sanctioned in Paris

1870 Degas reorganises Salon picture hanging to avoid the system of 'skying' and crowding paintings

1871 Arthur Rimbaud's poem 'Vowels' assigns colours to letters

1871-2 Claude Monet paints *Impression, Sunrise* (Musée Marmottan)

1873 First appearance of colour photography. Clerk Maxwell, *Electricity and magnetism.* Cézanne develops watercolour painting away from use of complementaries

1874 First Impressionist exhibitions: Monet, Renoir, Sisley, Pissarro, Cézanne, Degas, Guillaumin, Boudin, Morisot and others

1878 Hermann von Helmholtz and Ernst Brücke's *The Scientific Principles of the Fine Arts and Optics and Painting*

1879 Ogden Rood's *Modem Chromatics* (New York) (including quotations from Ruskin's 1857 book)

1881 Rood's book translated into French

1883 Frances Galton's *Inquiries into Human Faculty* (with its associations between colour, music and the spiritual)

1884-91 Signac and Seurat collaborations

1885 Charles Henry, poet and mathematician, *Introduction* to *a Scientific Aesthetic* Helmholtz and Brücke's book in its third edition

1886 *Musical Opinion* journal holds public debate on key-colour associations Charles Henry's *Law of the Evolution of Musical Sensations.*

1888 *The Aesthetic Recorder* given away free of charge and 'aesthetic protractor', compliments Charles Henry

1888-9 Charles Henry's Principles of a General Theory of Dynamogeny, that is on Contrast, Rhythm, and Measurement with Special application to visual and auditory sensations. Many of the charts for this drawn by Signac.

1889 Signac writes to Van Gogh regarding Henry's work.

1895 A. Wallace Rimington demonstrates his 'colour organ'

1996 Henry Bergson's *Matter and Memory*

1912 Wassily Kandinsky's *Concerning the Spiritual in Art*

1920s Paul Klee, *Notebooks* (published in *The Thinking Eye,* 1956)

1961 Johannes Itten's *The Art of Colour, The Subjective Experience and Objective Rationale of Colour*

1971 Josef Albers' *The Interaction of Colour* (now available as an iPad app)

1976 S. Ishihara Colour-Blindness tests

1977 Edward Land, *Retinex Theory of Color Vision*

8. **Preliminary Reference List: Colour theory and practice.**

Josef Albers — *Interaction of Color,* Yale 1971.

The most important work on colour tor be published by a practitioner since the scientific work by Edward Land in the late 1950s. The book was only available from specialist centres, but it can now be accessed as an iPad app.

Tim Armstrong — *Colour Perception:* A *practical approach* to *colour theory,* Diss, Norfolk, 1991. Includes cut out wheels and diagrams.

Vicki Bruce and Patrick Green — *Visual Perception, Physiology, Psychology & Ecology,* Hove 1985.

One of the best technical summaries on vision to date.

M.E. Chevreul — The Principles of Harmony and Contrast of Colours and Their Application to the Arts, 1839, trans. and introduction by Faber Birren, New York,. 1967.

A milestone in the history of colour and its uses in tapestry and painting e.g. in the work of Seurat. Some of the theory has now been proved incorrect.

Hugh Davson (ed.) — *The Eye, The Photobiology of Vision,* Volume 2B, A. Knowles and H.J.A. Dartnall, 'Requirements for the Visual Sense' and 'The Visual Pigment in the Receptor', New York, 1977.

Useful technical information.

David B. Dusenbery — *Sensory Ecology, How Organisms Acquire and Respond to Information*, New York, 1992

R.L. Gregory — *Eye and Brain, the psychology of seeing,* London 1972 (3rd edition) A now 'classic' summary of the subject.

Shinobus Ishihara — *Tests for Colour-Blindness,* Toyya, 1976.

Johannes Itten — *The Art of Colour, The subjective experience and objective rationale of color,* translated by Ernst van Haagen, New York 1961.

An eccentric but important work on colour theory and practice by an ex-Bauhaus teacher, painter and designer.

Johannes Itten — *Design and Form,* trans. John Maass, 1964. Useful summaries on light-dark and colour in painting.

Edwin H. Land — The Retinex Theory of Color Vision, San Francisco, 1977

Significant experimentation with colour by the inventor of the Land Polaroid Camera.

J.D. Mollon — 'Colour Vision', *Annual Review of Psychology*, 1982.

Good account of absorbance spectra of four photopigments of the normal human retina. Dispels misleading comments on "the primaries".

R. Clay Reid and Robert M. Shapley — *Nature* V. 356, no. 6371. 23/4/92, 'Spatial structure of core inputs to receptive fields in primate lateral geniculate nucleus'.

Particularly regarding how signals from cone photo-receptors are combined by neurons in the retina and brain.

Patricia Sloane — *Colour: basic principles and new directions,* London nd.

Useful introduction, particularly with regard to palette, but superseded by Wilcox.

R.C. Teevan and R.C. Binney (eds.) — *Colour Vision,* Van Nostraud, 1961.

Historical survey of texts from Young (1801) to Helmholtz (1878) and Edward Land (1959).

Helen Varley (ed.) — *Colour,* London 1988

A survey of issues and contexts.

Michael Willcox — *Blue and Yellow Don't Make Green: A new approach to colour mixing for artists,* Perth, 1987 (UK 1989)

Good for mixing paint. Good use of colour.

Ludwig Wittgenstein — *Remarks on Colour,* trans. Linda L. McAlister and Margarete Schüttle, University of California, Berkeley and LA, 1977 (1978).

Themes of colour features, colour kinds and curiosity leading to dispel the traditional idea that colour is a simple and logically uniform kind of thing.