Introduction

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Although the idea of 'colour' may seem a simple concept, it conjures up very different ideas for each of us. To the physicist, colour is determined by the wavelength of light. To the physiologist and psychologist, our perception of colour involves neural responses in the eye and the brain, and is subject to the limitations of our nervous system. To the naturalist, colour is not only a thing of beauty but also a determinant of survival in nature. To the social historian and the linguist, our understanding and interpretation of colour are inextricably linked to our own culture. To the art historian, the development of colour in painting can be traced both in artistic and technological terms. And for the painter, colour provides a means of expressing feelings and the intangible, making possible the creation of a work of art.

To comprehend the many aspects of colour, we must travel all the way from the hard sciences to the fine arts. Although these so-called 'two cultures' have frequently been seen as antithetical to each other, an exciting view to emerge from this volume is the convergence of ideas from disparate approaches. In the field of colour, the arts and the sciences now travel in unison, and together they provide a rich and comprehensive understanding of the subject.

On the scientific side, our path leads from the physics of light, through the biology of the nervous system and the intricacies of the mind, and on to the living organism in its environment. In the humanities, we traverse the history of colour in art, assess the role of our own culture and language in colour concepts, and experience the guiding principles of colour for a contemporary painter. Our path in these travels comprises essays by eight of the most eminent practitioners in their respective fields.

David Bomford, the Chief Restorer of Paintings at the National Gallery in London, introduces us to a history of colour in Western art. In the fourteenth and fifteenth centuries, two colour methodologies were introduced into painting. In 1390, Cennino described a system in which colours were used in their purest (saturated) form in the deepest shadows, and were then lightened progressively (de-saturated) with white in the lit areas, finishing with highlights of pure white. Half a century later, Alberti advocated a system in which the pure colour could either be modelled up with white, or instead down with black, in the lighter and darker regions respectively, with the pure colour occupying a position somewhere in the middle. Although Cennino's system remained the standard that characterizes tempera paintings, Alberti's more subdued method can be seen in the work of some painters of the time. A further theoretical insight attributable to Alberti was an elaboration of the concepts that we now call colour contrast and complementary colours, ideas that have been employed by successive generations of painters.

It was not only progress in ideas and theories that drove the evolution of painting, but technology also played a powerful part. The spread of oil-based painting in the fifteenth century provided artists with a whole new repertoire: a glossy, viscous medium, offering a wide range of colours and tones. Much later, in the eighteenth and nineteenth centuries, the blossoming science of chemistry provided a range of new synthetic pigments, which were rapidly adopted by the painters of the day. Not only has modern scientific analysis of paintings and pigments given us a fuller understanding of the techniques and materials used by painters, but it has also provided a formidable weapon in determining authenticity: a number of paintings have been shown to contain pigments not invented until after the death of the supposed painter.

How do the ideas and discoveries of the great painters of the past affect and influence a painter of the present? In this we are fortunate to be guided by one of Britain's most acclaimed contemporary artists, *Bridget Riley*. A painter has two quite different systems of colour to deal with: firstly, perceptual colour, i.e. colour as it is perceived by the observer viewing a natural scene; and secondly, pictorial colour, i.e. the use of the pigments from the palette to fabricate the appropriate sensation to the viewer. Over the centuries, the investigation of pictorial colour, by a relatively small number of painters, has led to some remarkable artistic adventures.

Titian, arguably the greatest colourist, introduced an incredible innovation by rendering colour inseparable from the forms depicted; he developed a style in which colour was used as a single element to shape and form the painting. A continual source of fascination is the way in which Titian allows a colour sensation to run through an entire composition, turning here warmer and there more subdued, subtly changing in hue, emerging now and then in strong tones, but winding through the work as a continuum. This development was to put European painting on a unique road – one reaching to the Impressionists and Post-Impressionists. The importance of Titian's discovery, and its subsequent evolution through the hands of later painters, is traced out by Bridget Riley with the passion of a practitioner of the art.

But what are the physical mechanisms that underlie the very existence of light and colour? *Malcolm Longair*, Jacksonian Professor of Natural Philosophy in the University of Cambridge, unravels our present understanding of light and colour as an historical development covering the last 400 years. The law of the refraction of light was discovered by Snell and Descartes early in the seventeenth century, and provided an explanation for the origin of rainbows. But the addition of colour to the rainbow did not come until later that century, when Newton's experiments with a glass prism showed that white light was composed of all the colours of the spectrum. In a remarkable burst of genius, the 22 year old developed the calculus in mathematics, the theory of colour in optics, and the theory of gravity in astronomy.

It was not until the nineteenth century that Thomas Young and Hermann von Helmholtz discovered the trichromacy of colour vision: the fact that any perceivable colour could be created by mixing together lights of only three different colours – this was a discovery not so much about light itself, but about the mechanism of human colour vision. Their ideas were put on a quantitative basis by James Clerk Maxwell, whose experiments on the mixing of colours form the basis of our current understanding.

How does the light that reaches our eye trigger a neural response, and what is the biological mechanism underlying the trichromacy of colour vision? The remarkable discoveries of recent years are described by *Denis Baylor*, Professor of Neurobiology at Stanford University. The retina lining the back of the eye contains sensory receptor cells: the rod and cone photoreceptors. The cone cells, which mediate daylight vision, comprise three types, sensitive to light in the red, green and blue portions of the spectrum. Electrical recordings from these microscopic cells, only one-thirtieth of the diameter of a human hair, have now revealed the complex chain of biochemical reactions that endow our photoreceptors with their exquisite sensitivity to light. The spectral properties of individual cones have been examined, and they are found to account precisely for the measured colour performance of the human observer – confirming exactly the ideas and observations of Young, Helmholtz and Maxwell last century. The human retina, although very thin, comprises a complex piece of computational machinery. Recent research has discovered the sequence of information-processing steps that the retina performs on colour and luminance signals. Thus, we now understand in considerable detail both the initial conversion of coloured light into a neural signal, and the subsequent processing of this information within the human eye.

But how are the neural signals that are sent from the eye processed and interpreted by the human brain? *John Mollon*, Reader in Psychology in the University of Cambridge, analyses the two separate colour systems that we are now known to possess – an ancient system shared by all mammals, together with a system that evolved more recently in our primate forebears. The older system provides dichromatic colour vision, by comparing responses from two classes of cones, while the newer system adds a further dimension to our colour vision, by bringing in the signals from the most recently evolved set of cones, sensitive at the red (or long-wavelength) end of the spectrum. By studying the performance of normal observers, as well as certain colour-anomalous subjects (including red/green deficient males and their mothers), it has been possible to determine the role and the relative importance of the two systems in different colour-recognition tasks. The ancient and modern systems, perhaps surprisingly, do not appear to correspond to the colour-opponent red/green and blue/yellow channels proposed by Ewald Hering.

In Nature, colour may be a source of great beauty to the beholder, but to a plant or an animal it is most often a means of survival. *Peter Parks*, a founder of Oxford Scientific Films and Image Quest, illustrates the magnificence of colour in Nature with stunning examples. Natural colour arises from a diversity of mechanisms, often associated with distinct functions. Dyes and stains are used by many creatures, frequently for camouflage. Structural colour – typified by the metallic sheen of a Mallard duck's blue speculum – is generally used for the intense colours that announce the presence of an individual, as for example in a mating display. Colour can also be used for warning, as in the poisonous fire-bellied toad, or even for mimicry. Less commonly, animals can dispense with colour altogether and become transparent, or, as in the squid, they can actively control skin colour for the purpose of camouflage, or for attraction and mating. Not only are the mechanisms and purposes multitudinous, but the effects are spectacular.

The discourse progresses next to the experience of colour by the observer, and to the meanings and ideas associated with particular colours. Why, for example, do we (in a Western culture) think of blue as cool, and red as warm? *John Gage*, Head of the Department of History of Art in the University of Cambridge, addresses these issues in terms of the relation between colour and culture. Even our concept of the number of different colours making up the rainbow seems to have arisen from a cultural factor – from Newton's desire to sustain the classical analogy between musical and optical harmony, between his scale of colours and the musical octave.

In some cultures, when specifying a colour, the texture of the object is more important, and the hue less important, than is the case in our own culture. And within Western culture, the enormous increase in interest in highly contrasting hues that was evident in the arts around the turn of this century probably arose from a combination of psychological and technological developments in society. So, colour and culture are inextricably linked.

All our concepts of colour are expressed in language. *John Lyons*, Master of Trinity Hall, Cambridge, explores the limitations placed on our understanding of colour, and on the naming of colours, by our use of language. No easy equivalents can be made between the colour-terms of different languages, and in English, a language rich in colour-terms, many are specific to particular contexts. A distinction needs to be made between the use of colour-terms to qualify an object (descriptive use) and the use of colour-terms to refer explicitly to a colour (referential use). In some languages, referential use is much less common than in languages such as English, and indeed many languages have no word for colour itself.

This leads him on to examine the influential thesis of Berlin and Kay that all languages recognise the same 'basic' colour-terms. He uses the examples of the modern Hanunoo language of the Philippines and Ancient Greek to show how words *translated* as simple colour-terms may include, in their original context, properties such as texture and luminosity. Thus *chloros* in Greek is usually translated to mean *green* in English, yet its meaning appears to refer to the freshness or moistness of green foliage, rather than to its colour. A difference in colour perception is not the cause of this language difference; the Greeks were not colour blind. It is instead a matter of language and culture whether the hue of an object is regarded as important, and indeed whether there is a name for it at all.

Thus the perception of *colour* is in the mind of the beholder, yet *colours* as we know them are a product of our language and our culture.

1 The History of Colour in Art

David Bomford

Introduction

It is almost impossible for us to know just how colourful the art of the past was. We can hardly begin to imagine how extraordinarily sumptuous mediaeval and Renaissance churches and palaces appeared – with their wall paintings, tapestries, painted architectural ornament, precious metals, enamels, and every kind of brilliant artifact. Any history of colour in art can only be partial, because so much art and so much colour in art has either perished or has survived only in a much changed form.

We have only to think of sculpture, for example, to see how our imagination fails us. With classical Greek and Hellenistic marble statues, it always comes as something of a shock to realise that they normally had realistically coloured lips, eyes, hair and clothes. We now usually imagine the antique through the practices of Renaissance and neo-classical artists, who saw Greek sculptures already stripped by time or the hand of Man of all their painted decoration. Polychromy of stone sculpture was certainly normal right up to and through the Romanesque and Gothic. It was only in the Renaissance – by a combination of mistaken interpretation of the nature of classical sculpture and a genuine interest in the natural textures and colours of materials that polychromy of stone sculpture died out. Very little intact medieval polychromy of carved stone survives, but where it is found – as in the great west portal of the collegiate church in Toro in north central Spain (The Portada de la Majestad, dating from the late thirteenth century), hidden for centuries under many layers of later polychromy – then the impact is astonishing.

Polychromy of wooden sculpture, of course, continued right through the Baroque and beyond. But a moment can be identified when one artist decided to strike out in a different direction. In mediaeval and early Renaissance Germany, it was usual for limewood sculpture and altar-pieces to be painted. Then, in 1490–2, Tilman Rimenschneider, the greatest of all the limewood sculptors, made the first known limewood retable in monochrome – the Munnerstadt altarpiece, which now survives only in fragmentary form. It was not entirely uncoloured: the pale wood was stained a little darker than its natural colour. But from then on, two traditions developed side by side and the more expert carvers revelled in the new unpainted freedom to show off the fineness of their carving and the subtle wood textures that they could produce.

There is an ironic sequel to Riemenschneider's making of the Munnerstadt altarpiece: eleven years later, the parish decided it was too plain, and in 1503 commissioned Veit Stoss to paint it in the old manner. His polychromy stayed on it for three centuries or more; then – we do not know precisely when – it was stripped off, a process that undoubtedly removed the original glaze beneath as well. Colour in art can be as untrustworthy as it is vulnerable.

Il libro dell' Arte: colour combinations based on pure pigments

Our best chance of constructing a coherent history of colour in art is to look at representational painting in all its forms from late mediaeval times to the twentieth century; the best place to start is with the most famous and influential treatise in the history of painting, *Il libro dell' Arte* written around 1390 by the Tuscan painter Cennino Cennini.

In his book, Cennino gives detailed instructions on the preparation of materials for painting in fresco and on panel. Learning to draw is important, he says, but working up the colours and painting with them is the 'glory of the profession'.

Cennino clearly describes systems of colour for depicting flesh, draperies, buildings and landscapes. Importantly, they are systems devised for painting in fresco and egg tempera – opaque, quick-drying media that were used in simple, direct techniques.

To paint faces, for example, Cennino describes how the flesh must first be underpainted with the pale green earth, terre verte. The pink flesh tones were then hatched or painted thinly on top, working in progressively paler shades from shadow to light; the green was allowed to show through in the half-tones and nicely imitated the pearly tones of real flesh. Today, many such faces are worn and damaged and the green has become too prominent. Cennino was very strict about this correct sequence for painting flesh: 'some begin by laying in the face with flesh colour – then they shape it up with a little verdaccio [*brown-green shadow colour*] and flesh colour, touching it in with some highlights and it is finished. This is a method for those who know little about the profession.' Later, in a famous passage, he recommends the pale yolk of a town hen's egg for painting the faces of young people with cool flesh colours, but the darker yolk of a country hen's egg for aged or swarthy persons.

Cennino's methods for painting coloured draperies were also highly specific, and formed the basis for painting the clothed figure right through the quattrocento and beyond. Essentially, colours were used in their pure form in the deepest shadows and then lightened progressively with white towards the lit areas, finishing with highlights of pure white. For its time, it was a remarkably successful scheme, but there were problems with it.

First, by placing the purest and most powerfully saturated colour in the deepest shadows and progressively desaturating it towards the lights, the shadows appeared to advance and the lights appeared to recede – the very opposite of the desired effect. Secondly, the relative brightness of the pure colours was very variable: this could lead to the unbalancing of compositions in which the brighter draperies, such as the yellows, stood out much more prominently than the darker ones, such as the blues. For this reason, painters often attempted a balance of symmetry, arranging their bright colours in pairs around a central axis – a scheme now termed *isochromatism*.

With the Cennino system, we thus have a series of colour combinations based on, and pre-determined by, the pure forms of the available pigments. Cennino describes the preparation of pigments from a variety of sources, both natural and artificial. Such colours could be readily available and inexpensive, or rare and cost a fortune: in the latter category, the best-known is ultramarine blue (literally, from 'over the sea', since it was then found only in Afghanistan), extracted from the semi-precious stone lapis lazuli and invariably (correctly) described as more expensive than gold. In late mediaeval times, when paintings were valued by the worth of their materials as much as the skill of their execution, the purest ultramarine was reserved for painting the Virgin's mantle and often costed separately in painter's contracts.

In such a painting as Lorenzo Monaco's *Coronation of the Virgin* (Figure 1), many of the available pigments are seen at full strength or mixed with white – coloured earths alongside ultramarine blues and the very beautiful lead-tin yellow. There was no green available powerful enough to compete with these strong colours and so areas of green tended to be mixtures of blue and yellow. Reds might be vermilion (an

Figure 1 Monaco, *Coronation of the Virgin.* (The National Gallery, London.)