

Philip Ball

## **The Invention of Colour**

The 2011 Van Gogh exhibition at the Royal Academy in London was widely praised for revising our view of the Dutch artist. Its central focus was a selection of Van Gogh's correspondence with his brother Theo, and these letters show that he did not work in a crazed frenzy, as the romantic legend might have us believe, but was methodical and thoughtful about his technique. The letters, which are of course long familiar to art historians, reveal a man passionate not so much about love and death as about art, and in particular about its techniques and materials. One great source of inspiration for Van Gogh was colours, especially the new colours that during his lifetime had only recently become available to artists. He wrote to Theo that:

I have got new ideas and I have new means of expressing what I want, because better brushes will help me, and I am crazy about those two colours, carmine and cobalt. Cobalt is a divine colour, and there is nothing so beautiful for putting atmosphere around things. Carmine is the red of wine, and it is warm and lively like wine. The same with emerald-green. It is bad economy not to use these colours, the same with cadmium.<sup>1</sup>

This focus on materials is not unusual among artists. Van Gogh's friend Paul Gauguin was preoccupied on Tahiti not with metaphysical questions – where we are from, where we are going – nor about his sexual relations with the local women, as again legend might encourage us to believe, but about the very prosaic difficulty of getting the pigments he needed.

There is a metaphor here for the way we traditionally think about art. Art historians have tended to analyse paintings in intellectual terms: what is the artist trying to say? What feelings is he or she attempting to convey? But painters themselves are more often concerned with the practical issues of creating a painting: of putting colours on canvas. How and where can they get their paints? Are those materials reliable? How much do they cost?

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1 Mark Roskill (ed.), *The Letters of Vincent Van Gogh*, p.252. New York, Simon & Schuster, 1997. p.252.

Over the course of the twentieth century we came to take the materials of art for granted. One may find racks upon racks of bright paint tubes in any art shop today. A close inspection of the labels reveals that many of the paints contain chemicals with complicated and daunting names: quinacridone, phthalocyanine. These are products of the modern chemical age, and were not available to Rembrandt – many of them, indeed, not even to Monet. Every time new colourants were discovered or invented, the possibilities for the artist expanded. But this was not an uncomplicated, linear process of accumulation. It was affected by factors such as cost, geographical availability, reliability and colourfastness of the material, and the degree of conservatism in the artist's technique. In this contribution I look at this issue of how art got its colours, and in particular I want to raise the question of how the invention of new colour has affected the directions that art has taken.<sup>2</sup>

It might seem strange to study art by looking at its materials. But that would not have been strange at all to painters of the Middle Ages or the Renaissance. They were deeply engaged with their materials, and out of sheer necessity, because they made their own paints from the raw materials. These painters knew that the quality of their art depended vitally on the quality of these materials. Although that is still true today, few contemporary artists have a comparable relationship with the physical characteristics of their medium. One suspects there is a perception almost of something vulgar about such tangible aspects of art. This means not only that some artists have undertaken ill-informed and disastrous experiments with paints, but also that art itself is in danger of losing touch with its roots as a practical craft.

## Colour in antiquity

The most ancient art we know of, such as that painted fifteen millennia ago in the caves of Lascaux (Fig.1), used pigments dug straight from the earth: ground-up minerals such as red and yellow ochre and chalk. These 'earth' colours are generally quite dull. The ochres are iron-rich minerals, chemically similar to rust. For black, cave artists usually used charcoal. And so the most common colours were those that nature offered most abundantly: black, white, red and yellow.

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<sup>2</sup> Philip Ball, *Bright Earth: The Invention of Colour*. London, Penguin, 2001.



Fig.1 *a*, Cave art from Lascaux, France, painted c.15,000 BC. *b*, Red and yellow ochre. These and all subsequent pigment images are kindly provided by L. Cornelissen & Son, London

In 1969, anthropologists Brent Berlin and Paul Kay claimed that colour words appear in all languages in the same sequence.<sup>3</sup> Some aboriginal languages distinguish only two colours: black and white. Others have three: black, white and red. When a fourth term is added to the language, it is always either yellow or green, followed by the other of these two. So the quartet of black, white, red and yellow corresponds to a kind of universal four-colour scheme – there are no languages with, say, terms for only red, yellow, blue and orange, or just red and blue. It seems unlikely to be just coincidence that these four basic colours are the ones that nature offers most readily.

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<sup>3</sup> Brent Berlin & Paul Kay, *Basic Color Terms: Their Universality and Evolution*. Berkeley, University of California Press, 1969.

The Egyptians used these pigments too, but they had a broader palette. Egypt in the third millennium BC had a surprisingly sophisticated chemical technology, because this was a product of the crafts that were central both to everyday and to religious life. In Egypt the artists were priests, and art was a devotional practice. Artworks were thought to acquire supernatural power through religious ceremonies. So the production of pigments was a socially important task.

One of the most renowned pigments of the ancient world was Egyptian blue (Fig.2), which is made by grinding up an artificial copper-containing compound: calcium copper silicate. This substance is made by melting sand together with copper minerals and chalk. It was probably discovered as an offshoot of the manufacture of blue-glazed stones called faience, which were first made in Mesopotamia around 4500 BC. Faience was used for decorative purposes, and stimulated experiments with materials and kiln designs that probably also lead to the discovery of glass and of copper smelting – the beginning of the Bronze Age.



Fig.2 *a*, Egyptian blue in *Hunting Birds in a Papyrus Thicket*, a wall painting from the tomb of Nebamun, 8th Dynasty (c.1567-1320 BC), Thebes. British Museum, London. *b*, Egyptian blue

So this blue pigment probably arose by chance as a side-product from a technology developed for making something else entirely. This is a common pattern for pigment discovery, which recurs right through to the twentieth century. Without the social demand for substances such as glass, soap, metals, dyes and plastics, it is unlikely that many of the technologies for pigment manufacture would have evolved, or would have been economically viable. The artist's palette is partly a by-product of industrial technology.

The Egyptians also knew how to use simple chemistry to make artificial whites, yellows, reds and greens, such as verdigris, made by letting vinegar fumes corrode copper. So their colour scheme was rather rich. The Greeks knew of these pigments, but they did not necessarily use them all. Some of the most renowned painters of classical Greece in 600-400 BC, such as Apelles, the court painter of Alexander the Great, chose deliberately to restrict their palettes to just four colours: the 'universal' black, white, red and yellow. Nearly all Greek painting has been lost now, but Figure 3 shows a Roman mosaic at Pompeii which reproduces an original Greek painting of Alexander, and it gives an impression of the muted Greek palette.



Fig.3 The 'Alexander' mosaic from the House of the Faun, Pompeii, a reproduction of a work by the Greek painter Philoxenos from the 4<sup>th</sup> century BC



It is not clear why this four-colour scheme was adopted. One suggestion is that, as the Greeks moved beyond the flat, two-dimensional pictograms of the Egyptians to depict three-dimensional shading, they found it difficult to achieve a harmonious balance of tones with too many colours. Whatever the case, the austere four-colour palette was eventually deemed the dignified and sober choice for serious artists, a prejudice that persisted in Imperial Rome. Pliny in the first century AD condemned artists who used so-called florid colours – even the reds and yellows, he said, ought to be earth colours rather than brighter pigments such as cinnabar which, ever since Alexander's conquests, could be imported from the East. Pliny feared that the sensuousness of Oriental colours would corrupt the supposed purity of artistic expression developed in classical Greece.

But unfortunately for Pliny, public taste was more vulgar, delighting in bright colour. His injunctions didn't stop craftsmen from using such colours for interior decorating, as we can see from the richly coloured wall fragments and murals that survive at Pompeii (Fig.4). Unfortunately, the mural techniques of the ancient world often fail to preserve the colours well. Exposed to sun and air, they fade, discolour or flake off, leaving buildings and statues bare of their original colours and making the classical world seem now like a much more drab, pale place than it really was.



Fig.4 Mural from the Villa of Mysteries, Pompeii, c.50 BC. Image © Kari Bluff.

## Magic and materials in the Middle Ages

Chemical technology thrived in what we have in the past mislabelled the Dark Ages, especially during the eighth and ninth centuries. These innovations happened not in the traumatized Christian West, but in the Islamic Middle East, where Arabic scholars mixed Greek philosophy with the practical skills that flourished in Alexandrian Egypt. They were blended in the art of alchemy.<sup>4</sup>

Even today alchemy is still widely misunderstood, being considered either as a misguided or fraudulent quest to make gold or as a metaphor for spiritual transformation. Some alchemy was certainly done by tricksters or deluded gold-makers, but it is now generally regarded by historians as having broader objectives. It is more aptly seen as pre-scientific chemical technology.<sup>5</sup> The Italian craftsman Cennino Cennini wrote a craftsman's manual describing the many pigments then available and how they might be obtained, made and used.<sup>6</sup> He mentions alchemy frequently, but it is clear that for him this is not an esoteric or mystical art but simply a convenient manufacturing method for his colours.

It is no coincidence that alchemists were making colours for artists, because colour is central to alchemy. To make the Philosopher's Stone – the substance that could allegedly transform base metals to gold – one had to conduct chemical reactions that would take the raw materials through a specified sequence of colour changes. So it is not surprising that the alchemists tended to focus their attention on the substances that offered a wide range of different colours. These turned out to be many of the same materials that artists were using as pigments.

Take lead, for instance. It was known since ancient times that exposing it to the fumes of vinegar and animal dung turned it white, owing to the formation of lead carbonate. This was known as white lead, and was the painter's finest white pigment until the nineteenth century.

But roasting white lead carefully in air will convert it to lead tetroxide, which is red. This pigment, called red lead, was used in the classical world at least since the second century AD.<sup>7</sup>

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4 Eric John Holmyard, *Alchemy*. Harmondsworth, Penguin, 1957.

5 Lawrence M. Principe, *The Secrets of Alchemy*. Chicago, University of Chicago Press, 2012.

6 Cennino Cennini (1370-1440), *Il Libro dell' Arte* (1437), translated by D. V. Thompson as *The Craftsman's Handbook*, New York, Dover, 1960.

7 Elizabeth West Fitzhugh, in Robert L. Feller (ed.), *Artists' Pigments: A Handbook of Their History and Characteristics*, Oxford, Oxford University Press, 1986, Vol. 1, p. 109-139.

Cennino Cennini says “it is manufactured by alchemy.” In medieval Latin it was called minium, and its extensive use in medieval illuminated manuscripts gives us the word “miniature”, although it is purely coincidental that these works were small – they simply had to fit on the page. Indian and Persian miniatures of the seventeenth to nineteenth centuries, which also feature red lead abundantly, are often finely detailed but not necessarily small.

Further roasting of red lead creates a yellow material: lead monoxide, or litharge. This was used in the Middle Ages as a pigment known as massicot. There now seems nothing extraordinary about these reactions of lead with various gases. But to the alchemists, they would have been seen as evidence of some fundamental change that was ‘purifying’ the lead, bringing it closer to the colour of gold (Fig.5).



Fig.5 Lead white (a), red lead (b) and litharge (c)

Yet the finest red pigment of the Middle Ages was, to the alchemists, perhaps the most fascinating substance of all. The Islamic alchemists instigated the notion that all metals are composed of two basic substances or ‘principles’: sulphur and mercury.<sup>8</sup> Alchemical or so-called ‘philosophical’ sulphur and mercury were abstract substances, not to be directly equated with the sulphur and mercury one could extract from the earth. But nevertheless, if these two raw elements are mixed together and heated, something miraculous happens. The dirty yellow sulphur and the silvery mercury combine to form a hard, blackish red material: mercury sulphide, which turns bright red when finely ground. Painters knew it as vermilion.<sup>9</sup>

<sup>8</sup> Robert P. Multhauf, *The Origins of Chemistry*. London, Oldbourne Book Co., 1966.

<sup>9</sup> Rutherford J. Gettens, Robert L. Feller & W. T. Chase, in Ashok Roy (ed.), *Artists’ Pigments: A Handbook of Their History and Characteristics*, Oxford, Oxford University Press, 1993, Vol. 2, p.159-182.



The eleventh-century Benedictine monk Theophilus describes the synthesis of vermilion in his own craftsman's manual.<sup>10</sup> He says:

take sulphur, break it up on a dry stone, and add to it two equal parts of mercury, weighed out on the scales. When you have mixed them carefully, put them into a glass jar. Cover it all over with clay, block up the mouth so that no fumes can escape, and put it near the fire to dry. Then bury it in blazing coals and as soon as it begins to get hot, you will hear a crashing inside, as the mercury unites with the blazing sulphur. When the noise stops, immediately remove the jar, open it, and take out the pigment.

This is surely as detailed as any later description of a standard laboratory synthesis, although it bears tell-tale signs of its alchemical origins in the (chemically incorrect) ratios specified for the two elements. Cennino, meanwhile, advises the painter to get vermilion ready-made from the alchemists – but not ready-ground, because some of them had a tendency to adulterate it with brick dust, to make it go further.

The art historian Daniel Thompson has claimed that the invention of vermilion was the central innovation of medieval art<sup>11</sup>:

No other scientific invention has had so great and lasting an effect upon painting practice as the invention of this colour... Given abundant vermilion, the standard of intensity in the painter's palette automatically rises. Equally brilliant blues and greens and yellows were required to go with it... If the Middle Ages had not had this brilliant red, they could hardly have developed the standards of colouring which they upheld; and there would have been less use for the inventions of the other brilliant colours which came on the scene in and after the twelfth century.

We can see how much medieval artists loved vermilion by the way they would apply it in flat swathes, for everyone to marvel at (Fig.6).

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10 Theophilus (c. 1122), *De diversis artibus*. Translated by J. G. Hawthorne & C. S. Smith as *On Divers Arts*, New York, Dover, 1979.

11 Daniel V. Thompson, *The Materials and Techniques of Medieval Painting*. New York, Dover, 1956, p.106-7.



Fig.6 *a*, Altarpiece attributed to Masaccio and Masolino (c.1423-8). St Jerome's drapery is rendered in vermillion. National Gallery, London. *b*, Vermilion

The aim of the medieval artist was not to paint 'realistically'. The subjects are almost always religious, and the artists themselves were often monks, or at least were hired by monasteries. They believed, as did the Egyptians, that paintings had a symbolic religious power, which was enhanced if one used the finest materials and displayed them unmixed. So medieval works are rich in vermillion and gold leaf – and, in the later Middle Ages, in a still more wondrous pigment: ultramarine (Fig.7).



Fig.7 Ultramarine made from lapis lazuli

Cennino says of this colour: 'Ultramarine blue is a colour illustrious, beautiful, and most perfect, beyond all other colours; one could not say anything about it, or do anything with it, that its quality would not still surpass.'

As its name implied, it came from 'over the seas', because the mineral from which it is made was not known in the West. Ultramarine is prepared from lapis lazuli, a blue stone found in Afghanistan. For centuries, all of Europe depended on the Afghan mines for their most precious pigment, which cost more than its weight in gold.

Ultramarine was precious not just because it was a rare import, but because it was extremely laborious to make. Most mineral pigments were made simply by grinding them up. But grinding raw lapis lazuli produces a disappointingly grey powder, because of the impurities that the mineral contains. These impurities have to be separated, which is done by kneading the powdered mineral with wax and washing the wax in water – the blue pigment flushes out into the water. This procedure must be repeated many times to fully purify the pigment.

In most of the altarpieces of the Middle Ages, the Virgin Mary is shown in blue robes (Fig.8). Many art theorists have attempted to explain the symbolic significance of the blue: that it conveys humility, virtue and so forth. But the main reason for this choice of colour is that the artist would naturally have lavished the most precious pigment on the most holy aspect of the painting.



Fig.8 Duccio, *The Virgin and Child with Saints Dominic and Aurea* (c.1315).  
The Virgin's robes are painted in ultramarine. National Gallery, London

### A new perspective

Ultramarine, vermilion and gold leaf might be considered the primary blue, red and yellow of the Middle Ages, the most precious colours a painter could acquire, and some altarpieces seem to use little else. But by the time of the High Renaissance, things were different. Titian's *Bacchus and Ariadne* (1523) (Fig.9) is one of the most radiant images in Western art, and shows why Titian is considered to be one of the finest colourists of all time.



Fig.9 Titian, *Bacchus and Ariadne* (1523). National Gallery, London

This is a completely different type of painting from those of the Middle Ages. We are now seeing people and places depicted realistically, which is to say, in an attempt to replicate how they would appear to a real observer of the scene. Light and shade, perspective, proportion and anatomy are all accurately observed. This is the key feature of the Renaissance humanism: actual human experience became the central concern of artists and writers, so that it was no longer sufficient to produce stylized, iconic works of art that paid only lip service to the shapes and forms of the world we live in. Renaissance artists put the viewer right in the picture.

This change meant that the materials of the painter no longer had the symbolic values of the Middle Ages. Ultramarine was now prized simply because it was a beautiful and pleasing colour – and because it showed off the wealth of the painter's patron – and not because its expense makes it a suitable

devotional offering to God. Gold leaf gradually disappears from use during the fifteenth century, since its costliness counted for nothing if it did not produce a realistic effect. Painters preferred to mimic gold using yellow, white and brown pigments.

And Titian's paints are totally different to those of medieval artists. Pigments have to be mixed with a fluid binding medium to make a paint. In the Middle Ages egg yolk was generally used as the binder for painting on wood. But Titian and his contemporaries mixed their colours with oils. Oil painting was perfected in Northern Europe in the early fifteenth century by the Flemish artist Jan van Eyck, and was gradually adopted by the Italians from around 1460. In the so-called egg tempera method the paints dry almost instantly, whereas oils are much slower to dry. This meant that colours could be blended and mixed, permitting the soft shadows and subtle shading that we see in Renaissance art.

The use of oils also compelled some changes in pigment use, because some colours look different when bound in oil from when bound in water or egg yolk. In particular, both ultramarine and vermilion are more transparent and less brilliant in oil. This forced painters to adulterate ultramarine by mixing it with a little lead white to keep it strong and opaque, which helped to erode its mystique. As a result, artists began to feel more free to use a whole range of lighter blues in their works. The art historian Paul Hills says that "Blue by the fifteenth century was moving away from its association with starry night, the vault of the heavens, to the changeful sky of day."<sup>12</sup> This was a change in colour use instigated by the physics and chemistry of the artists' materials.

But there were other reasons why Titian and his contemporaries had a wider range of colours available than most medieval artists. Titian lived and worked in Venice, which along with Florence was the artistic capital of Renaissance Italy. Venice was a major port where many of the rare spices, foods, textiles and pigments from the East first arrived. So the Venetian artists had first pick of the best colours, and they made abundant use of materials that came from the Arabic nations. This made Venetian art extremely colourful. In Florence, on the other hand, where Leonardo da Vinci and Michelangelo worked, there was greater emphasis on line – on drawing skills – than on colour. The art world of the Renaissance initiated a long-lasting debate on the relative merits of colour and line in art, which resolved itself around the seventeenth century in favour of skill at drawing as the artist's most important attribute, with colour being merely a secondary consideration. This cast a shadow over the use of colour in art until the nineteenth century.

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12 Paul Hills, *Venetian Colour: Marble, Mosaic, Painting and Glass, 1250-1550*, New Haven, Yale University Press, 1999, p.136.



But during the fifteenth and early sixteenth centuries Venetian art was full of bright colour. In *Bacchus and Ariadne* Titian uses just about every one of the pigments then available, and in doing so he provides us with a map of the state of sixteenth-century chemistry.

The brilliant blue sky is ultramarine, as is Ariadne's robe. But the sea, which has a greenish tint, is painted in azurite, a blue copper mineral known since ancient times (Fig.10). This is a cheaper pigment, although the best grades were still quite expensive. There were azurite deposits in several places in Europe, including France, Hungary, Germany and Spain. Imported ultramarine rarely made it all the way to Northern Europe, at least at an affordable price, and so most of the blues in the works of German and Dutch artists in the Renaissance are azurite.

There is vermilion here too, in Ariadne's scarf, but also another kind of red pigment: red lake. This is made from red dyes, which are organic materials. Some red dyes were extracted from plants, such as brazil wood and madder root (Fig.10).<sup>13</sup> Others came from animals: cochineal was made in the sixteenth century from ground-up dried beetles, and *lac* or *lacca*, from which lake gets its name, was a resin secreted by certain tree-dwelling insects from Asia and the Middle East. These dyes were converted to lake pigments by dissolving the colouring agents in water and fixing them onto the surface of fine particles of a white powder. This procedure was known in the Middle Ages, but was not perfected until the Renaissance. Red lakes are darker and richer than vermilion; a common red lake known as kermes supplies the root of the word 'crimson'. Lakes are translucent when used in oils, and Renaissance painters often used them as translucent glazes to give rich flesh tones or to make purples by red glazing over blue.

Renaissance yellows were typically compounds of lead, tin and antimony, which the Egyptians had known how to make. But in *Bacchus and Ariadne* there is also a brighter, richer golden yellow called orpiment (Fig.10), which is arsenic sulphide: the name means "pigment of gold".<sup>14</sup> It can be found naturally in mineral form, but a better-quality pigment could be had by making orpiment synthetically. Its manufacture was surely an alchemical discovery, as Cennino hints. It is highly poisonous, and some painters avoided it for this reason. Cennino warned painters to 'Beware of soiling your mouth with it, lest you suffer personal injury'. In view of this and its high cost, orpiment is quite rare in Renaissance art, particularly in Northern Europe. One Northern painter who did make

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13 Helmut Schweppe & John Winter, in Elizabeth West Fitzhugh (ed.), *Artists' Pigments: A Handbook of Their History and Characteristics*. Oxford, Oxford University Press, 1977, Vol. 3, p. 109-155; Helmut Schweppe & Heinz Roosen-Runge (1986), in R. L. Feller (ed.), *Artists' Pigments*, Vol. 1, p. 255-283.

14 Elizabeth West Fitzhugh, *Artists' Pigments*, Vol. 3, p. 47-80.

use of it is Lucas Cranach, who had better access to it than most others because he also ran a pharmacy, and was therefore knowledgeable in the materials and methods of alchemy.

Also in this picture is the only pure orange pigment known until the nineteenth century – painters otherwise had to make orange by mixing red and yellow. The orange in the robes of Titian's cymbal-player is realgar, which is a different form of arsenic sulphide (Fig.10). It also occurs naturally, and was imported to Europe through Venice from Romania and the East. Because it was so poisonous and expensive, it is rather rare in Western art.

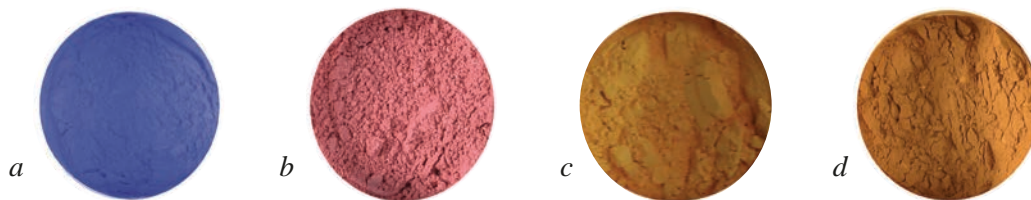


Fig.10 Titian's pigments included azurite (a), red lake (b – here madder), orpiment (c) and realgar (d)

## The fall and rise of colour

Colour use during the seventeenth and eighteenth centuries became subdued relative to the exuberance of the Renaissance. Rubens often painted as brightly as Titian, but we remember this period mostly for the more subdued palettes of Rembrandt, van Dyck and Poussin. There was not much innovation in pigment manufacture during this time, and it is interesting that several of the new pigments that did appear were in the autumnal colours typical of Rembrandt.<sup>15</sup> The prevailing attitude of the connoisseurs by the early nineteenth century was summed up by Sir George Beaumont, an artist and a patron of John Constable, who said that "A good picture, like a good fiddle, should be brown".<sup>16</sup>

Constable was apparently eager to please his patron (Fig.11). If pictures were not brown enough already, Victorian conservators often made them so with a coat of muddy varnish. In Constable's

<sup>15</sup> R. D. Harley, *Artists' Pigments c.1600-1836*, 2nd Edn., London, Butterworths, 1982.

<sup>16</sup> Richard Redgrave & Samuel Redgrave, *A Century of Painters of the English School*, London, Smith, Elder & Co., 1866, Vol.1, p. 11.

defence, he is said to have protested by taking a violin and placing it on grass to show how different the two colours were. But nevertheless he observed the convention that expected artists to tone down their colours. The fact that he was actually considered an innovator with an unusually bright palette tells us how truly murky colour had become by the early nineteenth century.



Fig.11 John Constable, *The Cornfield* (1826). National Gallery, London.

Let us have a look at these autumnal colours. Baroque painters who liked their works dark and golden could use Cassel earth, a peaty substance with a warm brown colour that Van Dyck liked so much that it later became known as Vandyke brown (Fig.12). Some unfortunately turned to bitumen, an oily, organic brown pigment that never dried and ended up ruining several nineteenth-century paintings, such as Gericault's *Raft of the Medusa*. Indian yellow was a mysterious, odd-smelling substance (Fig.12) imported from India by the Dutch and used by Rembrandt, which in the nineteenth century was found to be made from the urine of cows fed exclusively on mangos.<sup>17</sup>

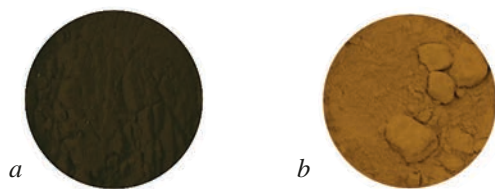


Fig.12 Baroque colours: Cassel earth/Vandyke brown (a) and Indian yellow (b)

But in the late eighteenth century, a new rainbow began to spread across the artist's palette. This was the golden age of chemistry, when many new elements were being discovered and the French chemist Antoine Lavoisier was starting to make sense of chemical transformations through his discovery of the element oxygen. That discovery is contentious; some claim that the first person to identify oxygen was the Swedish apothecary Carl Wilhelm Scheele, one of the greatest experimental chemists of his time. Scheele also isolated hydrogen, barium and chlorine, which was soon used by the dyeing industry as a bleach. And in 1775 Scheele discovered a green substance while experimenting on arsenic compounds. This was copper arsenite, which soon became used as a green pigment called Scheele's green.<sup>18</sup> It was brighter than any of the earlier pure green pigments – until then, many painters had made greens instead by mixing blue and yellow.

Scheele's green was eclipsed by the discovery in 1814 of a new, more attractive arsenic-based pigment, which became known in England as emerald green or Paris green (Fig.13). Both of these 'arsenic greens' were potentially poisonous: if exposed to dampness, they could be decomposed by moulds to give off a toxic gas. Because they were quite cheap to manufacture, emerald green and Scheele's green were used not only as artist's paints but as household paints and on patterned wallpaper. It has been claimed that this made damp rooms hazardous, and in the 1860s there were fears in England that young children were being killed by the deadly fumes being released from their

17 Norbert S. Baer, A. Joel, Robert L. Feller & N. Indictor, in R. L. Feller (ed.), *Artists' Pigments*, Vol. 1, p. 1-36.

18 Inge Fiedler & Michael Bayard, in E. West Fitzhugh (ed.), *Artists' Pigments*, Vol. 3, p. 219-272.

bedroom walls. Whether arsenic greens were quite as dangerous as has been claimed is, however, still a contentious issue.<sup>19</sup>

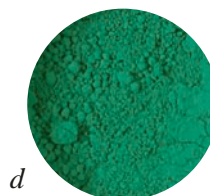
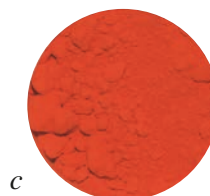
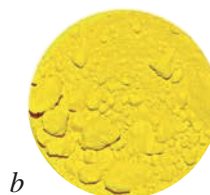


Fig.13 Paris green

Perhaps the most important innovations in artists' colours in the nineteenth century stemmed from the discovery in the late eighteenth century of a bright red mineral from Siberia, called crocoite or Siberian red lead (Fig.14a). In the early nineteenth century the French chemist Nicolas Louis Vauquelin investigated crocoite and discovered that it contained a new metallic element whose compounds were brightly coloured. For this reason he proposed the name *chrome*, from the Greek word for colour. The element is now known as chromium.



Fig.14 a, Crocoite (natural lead chromate). National Museum of Natural History, Smithsonian Institution, Washington.  
b, Chrome yellow. c, Chrome orange. d, Viridian



<sup>19</sup> W. R. Cullen & R. Bentley (2005). *J. Environ. Monit.* **7**: 11-15.

Crocoite is a mineral form of lead chromate. When Vauquelin made this compound synthetically, he found it had a bright yellow colour (Fig.14b). This became used as a pigment called chrome yellow<sup>20</sup> – not just for artist's paints but also for commercial ones. It was widely used to paint coaches, for example, anticipating its use on the yellow taxi cabs of New York.

Vauquelin found he could also make a different form of lead chromate that was orange – the first pure orange pigment since poisonous realgar (Fig.14c). And chromium oxide was a green colour. With a little water incorporated into the crystals, this provided the rich green pigment called viridian in England (Fig.14d).

The bright chromium colours were augmented by several others in the early nineteenth century. In 1817 the German chemist Friedrich Stromeyer discovered a new element called cadmium, a by-product of zinc smelting. He found that this metal could be combined with sulphur to make bright yellow and orange pigments called cadmium yellow and cadmium orange (Fig.15).<sup>21</sup> In the early twentieth century a deep red version became available, and grew rather popular; Matisse was particularly fond of it.



Fig.15 The cadmium colours: yellow (a), orange (b) and red (c)

In the late eighteenth century the French government considered pigment manufacture so commercially important that it appointed leading chemists to devise new ones. The government asked Louis-Jacques Thénard to look for a synthetic substitute for expensive ultramarine. In 1802, Thénard found a way to make a rich blue colour from cobalt, which became known as cobalt blue (Fig.16). Cobalt offered several other colours too: in the 1850s a cobalt-based yellow pigment called aureolin became available in France, soon followed by a purple pigment called cobalt violet, the first ever pure purple pigment. A sky blue pigment called cerulean blue (Fig.16), made from cobalt stannate, was a favourite of some of the post-Impressionists.

20 Hermann Kühn & Mary Curran Lead, in R. L. Feller (ed.), *Artists' Pigments*, Vol. 1, p. 187-217.

21 Inge Fiedler & Michael Bayard, in R. L. Feller (ed.), *Artists' Pigments*, Vol. 1, p. 65-101.



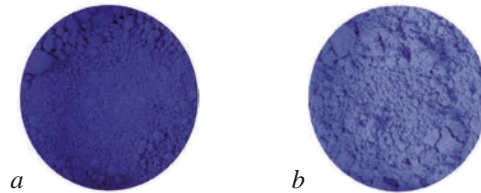


Fig.16 Cobalt blue (a) and cerulean blue (b)

What painters really wanted for a blue, however, was a cheaper form of ultramarine itself. In 1824 the French Society for Encouragement of National Industry offered a prize for the first practical synthesis of ultramarine. It is a complicated compound to make – the blue colour comes not, as in most pigments, from the presence of a particular metal in the crystals, but from the presence of sulphur. In 1828, a Frenchman named Jean Baptiste Guimet claimed the prize, which is why synthetic ultramarine was subsequently widely known as French ultramarine.<sup>22</sup>

So pigment manufacture was no longer a cottage industry performed by apothecaries, but a major industrial enterprise. Factories were set up in the nineteenth century to make and grind pigments. Some sold them in pure form to the artist's suppliers, who would then mix up paints for their customers from pigment and oil. But some pigment manufacturers, such as Reeves and Winsor & Newton in England, provided ready-made oil paints which, from the 1840s, were sold in collapsible tin tubes.<sup>23</sup>

These developments meant that painters became ever less familiar with what it was they were buying, and had no way of assessing the quality of this profusion of new paints. And so a new breed of professional began to appear: the colourman, who knew the skills of the painter but also possessed some chemical knowledge that allowed him to test the materials that he supplied to artists. In England, the foremost colourman of the nineteenth century was George Field, who supplied paints to J. M. W. Turner and the Pre-Raphaelites.<sup>24</sup> We can readily see the difference these colours made if we compare John Millais's *Ophelia* (Fig.17) to Constable's landscapes less than 20 years earlier (Fig.9). Notice in particular how vibrant the greens have become – too vibrant, in fact, for some tastes, as evidenced by Ford Madox Brown's comment that Millais was using greens "unripe enough to cause

<sup>22</sup> Joan R. Mertens (2004), *Ambix* 51, 219-244.

<sup>23</sup> David Bomford, Jo Kirby, John Leighton & Ashok. Roy, *Art in the Making: Impressionism*. London, National Gallery Publications, 1990.

<sup>24</sup> John Gage, *George Field and His Circle*. Cambridge, Fitzwilliam Museum, 1989.

indigestion”.<sup>25</sup> These painters relied on Field’s advice on the reliability of the new materials – whether, for example, they would rapidly fade or discolour on the canvas. It was because of Field’s assistance that Turner was able to acquire the new colours almost as soon as they were invented, and he was amongst the first painters in England to use cobalt blue, emerald green, viridian, chrome yellow and others.<sup>26</sup>



Fig.17 John Everett Millais, *Ophelia* (1852). Tate Gallery, London

A willingness to embrace these new materials is part of the reason why Turner brought a blaze of Venetian brightness to the dour early nineteenth-century palette. His *Ulysses Deriding Polyphemus* (1829) (Fig.18) was considered shocking by many contemporary critics: one of them called it “a specimen of colouring run mad – positive vermilion – positive indigo; and all the most glaring tints of green, yellow and purple”.<sup>27</sup> Joris-Karl Huysmans, a prominent art critic at that time, was more perceptive, comparing Turner to “a Rembrandt born in India”.<sup>28</sup>

25 Elizabeth Prettejohn, *The Art of the Pre-Raphaelites*, London, Tate Publishing, 2000, p.148.

26 In John Gage, *Colour in Turner: Poetry and Truth*, New York, Praeger, 1969, p.123.

27 Ibid.

28 In John Gage, *Colour and Meaning: Art, Science, and Symbolism*, London, Thames & Hudson, 1999, p.162.



Fig.18 J. M. W. Turner, *Ulysses Deriding Polyphemus* (1829). National Gallery, London

Turner's use of colour influenced the Parisian Impressionists such as Monet, who came to London to see his work. The Impressionists made equally avid use of the new colours. The shock of seeing their work was not just that of seeing a new style of painting, without the clear edges and smooth finish favoured by the French Academy of Fine Arts, but also of encountering colours never before seen on canvas. In Renoir's *Boating on the Seine* (Fig.19), there are just seven pigments apart from the traditional lead white, and all but the reds are "modern" synthetic colours: cobalt blue, viridian, chrome yellow, "lemon yellow" (strontium chromate) and chrome orange (basic lead chromate). They are applied almost unmixed, and the impact of the new pure orange is very apparent in the boat's outline placed against the cobalt blue river. This is Impressionism straight from the tube.



Fig.19 Pierre-Auguste Renoir, *Boating on the Seine* (1879-80). National Gallery, London

The Impressionist style shaped the early work of many of the most important painters of the modern age. Paul Cézanne began as an Impressionist, and Vincent van Gogh's work was transformed when he came to Paris and saw these paintings. They gave him the inspiration to use bold, unmixed new colours with glaring brilliance (Fig. 20). With the harsh dissonances in this work, called *The Night Café*, Van Gogh said that "I have tried to show that the café is a place where one can ruin one's self, go mad, or commit a crime."<sup>29</sup>

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29 Quoted in John Rewald, *Post-Impressionism: From Van Gogh to Gauguin*, New York, Museum of Modern Art, 1978, p. 210.



Fig.20 Vincent van Gogh, *The Night Café* (1888). © Yale University Art Museum

Henri Matisse was an Impressionist early in his career, but he later used the new pigments to yet more stunning effect as the figurehead of the movement known as the Fauves (“wild beasts”), reflecting their uninhibited use of bright colour (Fig.21). Fauvism made colour a central constructive component of modern art. Kandinsky initially painted in the Fauve style, and later attempted to identify a universal emotional language of colour. None of this would have been possible without the development of the vibrant new pigments in the nineteenth century.





Fig.21 Henri Matisse, *Le Bonheur de Vivre* (1905-1906). © Succession H. Matisse /DACS 2012.  
Image © 2012 The Barnes Foundation.

## Living and dyeing

This explosion of colour was not confined to fine art. As chemistry blossomed, it brought colour into the world at large, particularly when chemists discovered in the mid nineteenth century how to make new dyes from the aromatic hydrocarbons found in coal tar, the black residue from gas-lamp burning.<sup>30</sup> These new dyes engendered fashions in dress that would strike us as garish today. Women took to the streets in voluminous dresses and gowns of purple, magenta and other rich colours. The 1850s were dubbed the Purple Decade, an epithet reflected in *April Love* by the Pre-Raphaelite Arthur Hughes (Fig.22).

<sup>30</sup> See Anthony S. Travis, *The Rainbow Makers*. Cranbury, NJ, Associated University Presses, 1993.



This picture was painted in 1856, and it was in that year that the first coal-tar dye was synthesized by William Perkin, who was just eighteen years old at the time and studying at the Royal College of Chemistry under the German chemist August Wilhelm Hofmann. He discovered the coal-tar dye that became known as mauve while trying to make the anti-malarial drug quinine at Hofmann's instruction, and he immediately quit his studies and set up in business with his father and brother at a factory in Harrow.<sup>31</sup> The gamble paid off, and half a century later Perkin was a rather shy and reluctant celebrity, regarded as one of the greatest organic chemists of the age (Fig.23).



Fig.22 Arthur Hughes, *April Love* (1856).  
Tate Gallery, London.

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31 See Simon Garfield, *Mauve*. London, Faber & Faber, 2001.

Perkin initially tried selling the dye under the name Tyrian purple, harking back to the legendary purple dye of Imperial Rome, extracted from Mediterranean shellfish. But there was now more to be gained by association with Parisian haute couture than with Classical antiquity, and the word mauve comes from the French for mallow.

The rise of coal-tar dyes was accompanied by the chemical synthesis of the colouring agents in common natural dyes. In 1868 chemists made alizarin, the molecule that gives madder

red its colour; and in 1877 indigo was synthesized. This led to the collapse of dye-growing industries in Europe and in the British colonies in India. But it also spawned the entire modern chemicals industry. The commercial call for dyes was immense, and dye manufacturers thrived. Towards the end of the century they began to diversify into new areas, particularly pharmaceuticals. In 1909 Paul Ehrlich discovered the first synthetic drug – Salvarsan, a cure for syphilis – while using synthetic dyes to stain cells. Most of the major European chemicals companies – Hoescht, BASF, Agfa, Bayer, Ciba-Geigy – began their lives as dye manufacturers (Fig.24). One might reasonably say that not only did chemistry give us colour, but the quest for colour gave us modern chemistry.



Fig.23 Portrait of William Henry Perkin by Arthur Stockdale. National Portrait Gallery, London.



Fig.24 A selection of early dye samples from the German company Farbenfabriken Bayer & Co., Elberfeld.  
Courtesy of Bayer corporate History & Archives, Leverkusen.

## Twentieth-century blues

The pigments of modern times encode their own stories about how art evolved in the twentieth-century. One might think of the Day-Glo colours of Andy Warhol and Roy Lichtenstein, or the impact of new synthetic paint media like acrylics and alkyds on the colour choices of the Abstract Expressionists and their successors.<sup>32</sup> In the 1950s American artists such as Frank Stella began to use household paints made with these new resins, and so their palettes lay at the mercy of the commercial paint companies. But I shall conclude with a single modern parable about chemistry and colour in art: the story of the world's most beautiful blue.

Yves Klein was never an artist in the league of Turner, Rembrandt or Titian, but he is remembered for one thing: International Klein Blue, which he used for a series of monochrome paintings in the 1950s (Fig.25).

<sup>32</sup> Jo Crook & Tom Learner, *The Impact of Modern Paints*. London, Tate Gallery Publishing, 2000.

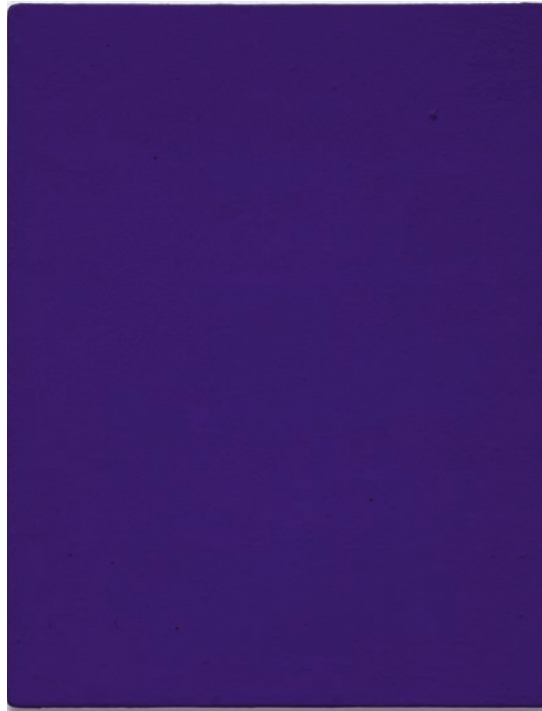


Fig.25 Yves Klein, *IKB 82* (1959). Solomon R. Guggenheim Museum, New York. Gift, Andrew Powie Fuller and Geraldine Spreckels Fuller Collection 2000.<sup>27</sup>

This colour simply cannot be done justice in any reproduction – one must see it at first hand to appreciate how lustrous it is. Klein believed that colour alone was sufficient to say all he wanted to say, without the distraction of line and form. In 1954 he said,

I believe that in future, people will start painting pictures in one single colour, and nothing else but colour.<sup>33</sup>

And that is just what he did.

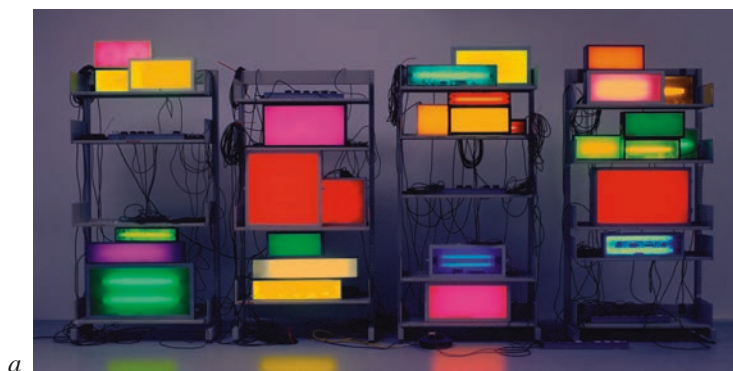
Klein's blue is in fact none other than ultramarine – the synthetic version of ultramarine devised in the nineteenth century. But ultramarine never looked like this before – at least, not on

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<sup>33</sup> Hannah Weitemeier, *Klein*, Cologne, Taschen, 2001, p. 9.

the canvas. Klein realized that pigments always tend to look richer and more gorgeous as a dry powder than when mixed with a binder, and he wanted to find a way to capture this appearance in a paint. In 1955 he found his answer: a new synthetic fixative resin made by the Rhone-Poulenc chemicals company, which could be thinned to act as a binder without impairing the chromatic strength of the pigment. This gave the paint surface a matt, velvety texture. Klein collaborated with a Parisian chemical manufacturer and retailer of artists' materials named Edouard Adam to develop a recipe for binding ultramarine in the resin mixed with other organic chemicals.<sup>34</sup> To protect this mixture from misuse that would compromise the purity of his idea, he patented it in 1960.

Fig.26 New directions in colour:  
*a*, David Batchelor, *Brick Lane Remix* (2003), Courtesy of David Batchelor; *b*, Anish Kapoor, *As if to Celebrate, I Discovered a Mountain Blooming with Red Flowers* (1981), © Tate Gallery/DACS.



<sup>34</sup> Nicolas Charlet, *Yves Klein*. Paris, Vilo International, 2000.

The significance of this episode in art history is to show not only that some artists were still depending on chemical assistance in the modern era, but also that the intimate relationship of painters to their materials has not been entirely severed. Today painting is an unfashionable art. Young artists want to work in sculpture, installation and video. While this does lead to some interesting new directions for colour – for example, employing coloured light, or raw pigments (Fig.26), or rainbow-like refraction as in Andy Goldsworthy's *Rainbow Splash* (1981) – it is hard to imagine that paint has nothing more to say about it.

There are still painters who care deeply about colour and paint, but they are few, and rarely young – one might think of Bridget Riley, David Hockney, Howard Hodgkin. In an age when painters have more choice of materials than ever before, this might seem strange. But perhaps in a way that surplus of choice might contain the very problem: artists have lost confidence in paint because they no longer feel they understand it. How different this is from the spirit apparent in an account by the photographer Brassai of a conversation with Picasso:

Then the man in the blue suit reaches into his pocket and takes out a large sheet of paper, which he carefully unfolds and hands to me. It is covered with Picasso's handwriting - less spasmodic, more studied than usual. At first sight, it resembles a poem. Twenty or so verses are assembled in a column, surrounded by broad white margins. Each verse is prolonged with a dash, occasionally a very long one. But it is not a poem; it is Picasso's most recent order for colours...

For once, all the anonymous heroes of Picasso's palette trooped forth from the shadows, with Permanent White at their head. Each had distinguished himself in some great battle - the blue period, the rose period, cubism, 'Guernica'... Each could say: 'I too, I was there...' And Picasso, reviewing his old comrades-in-arms, gives to each of them a sweep of his pen, a long dash that seems a fraternal salute: 'Welcome Persian red! Welcome emerald green! Cerulean blue, ivory black, cobalt violet, clear and deep, welcome! Welcome!'<sup>35</sup>

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<sup>35</sup> Quoted in *Picasso and Company*, transl. F. Price, New York, Doubleday, p.87.