CHAPTER 5

New science on offer

Introductory

This chapter provides a brief introduction to the science that underpins the late nineteenth century revolution in the way artists approached the use of colour in paintings. A major catalyst to their innovations was Georges Seurat's ***game-changing approach to the problem of creating illusions of a light-filled space****. As later chapters will explain in detail, the key ideas shift was that, rather than follow his predecessors in seeking to do this by means of variations in lightness alone, Seurat introduced colour into the process. But this was not all, for there were a number of unforeseen spin-offs of his method of doing so. One was a* ***huge increase in the range and the subtlety of colours and the colour relations used by artists****. Another concerned the* ***handling of the real surface/illusory space dynamic****. Both had profound implications for the future of painting.*

Isaac Newton's demonstration

As explained in the preceding chapter, in the period from the 15th century to the mid nineteenth century, the community of artists, following the lead of *the Masters of the Italian Renaissance* saw no role for colour in the depiction of effects of space and light, except in the case of blue used in the context of aerial perspective. A main reason for this state of affairs was the embryonic state of colour theory. It was not until the nineteenth century that fundamental shifts in ideas concerning the nature of colour gained momentum and began to have a transformative effect on its use in paintings.

The first big step in this was taken towards the end of the 17th century by Isaac Newton when he used a prism to establish that "white" light contains all the colours of the rainbow.

Figure 1 shows that a beam of white light which passes either through a prism or through a cloud of rain droplets will be broken up into "*all the colours of the rainbow*". It is now known that is because: (a) ***White light*** contains a continuum of different wavelengths; (b) Each of them is bent differently as it passes first from the air into the glass and then back again from the glass into the air. And, (c) the different receptor-types in the retina that are stimulated differentially by these. As the diagram indicates, short wavelengths (blue) are bent the most and long ones (red) the least.

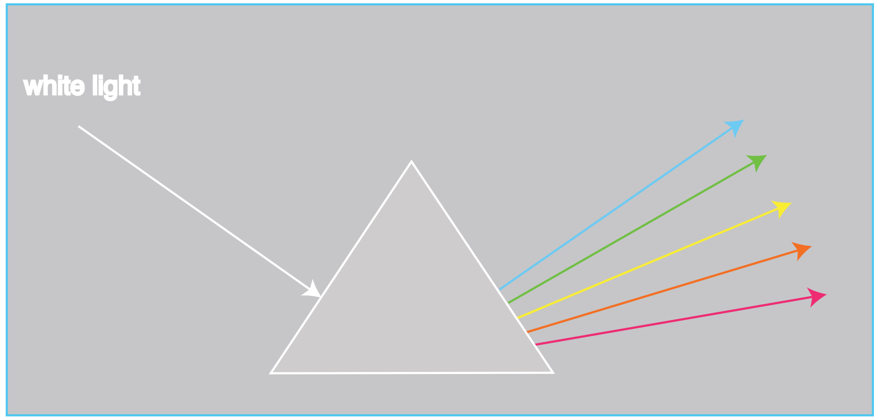

Figure 1 : The creation prismatic colours from a beam of white light.

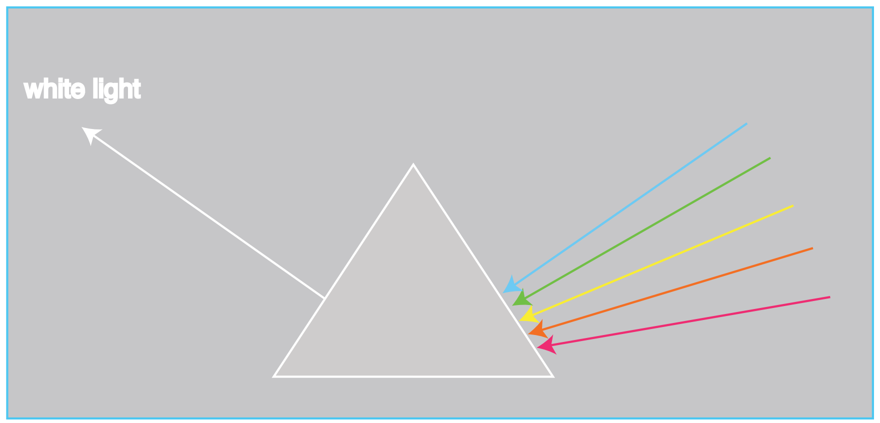

Figure 2 : The creation of a beam of white light by recombining the prismatic colours

Figure 2 illustrates Isaac Newton's demonstration that, if the prismatic colours are passed back through the prism, they will recombine into white light. Apart from being interesting in itself, this transformation also suggests one of the basic facts of what is known as *additive colour mixing*, namely that *mixtures are always brighter than the colours from which they are made* (see *Figure 3*).

Although Newton's demonstration was soon recognised as being of fundamental importance for scientists, it had little effect on artists until its findings became central to the ideas of Seurat in the 1880s. What he deduced from Newton's experiment was that, if he wanted to paint white light, he would need to represent all the colours of the spectrum..

The discovery of colour

When doing his experiments Newton assumed that colours are a property of light (and, presumably, of surfaces in the external world). However, towards the end of the 18th century, scientists began to notice phenomena which did not fit with this assumption. The key breakthrough came from a crop of observations of what came to be known as "***induced colour***". These led rapidly to the widespread acceptance of the idea that colour is somehow made in the eye (and, perhaps, the brain). Particularly influential on artists were the writings of Goethe, the German, poet, playwright and scientist. In his book "*Zur Farbenlehre*",[1] which was published in 1810, he told of various key observations. On one occasion, after staring fixedly at a beautiful woman in a red dress, he was startled, when she moved away, to see a vivid, green *after-image* on the blank, white wall behind where she had been sitting. On another he noticed violet shadows in a scene illuminated exclusively by a yellow candle flame. Neither could be explained by Newton's ideas. The only place such colours could be manufactured was inside the head.

But Goethe was by no means the only researcher who had noticed such things and was certainly not the first. The most impressive of them all was the French mathematician and scientist, Gaspard Monge (1746-1818) who as early as 1789, gave two, mould-breaking demonstrations to the French "*Académie Royale des Sciences*". Both were very simple. In the first, he asked his audience to look at piece of red card through a piece of red glass. Much to their surprise the red became "*white*" (not an intensified red as they were expecting). In the second demonstration, Monge related this counter-intuitive phenomenon to another, which can be demonstrated as follows. First, focus two beams of white light from

1 Translated as "*The Theory of Colours*".

two separate projectors on the same white-coloured screen. In one of the projectors place a filter that blocks out all but the long wavelengths of light coming from it, thus creating a red beam. In this, place a table tennis bat or some other opaque object so that it casts a shadow on the screen. Since the shaded region is illuminated only by the white beam, common sense would indicate that it would appear to be white or grey. But it will not do so. Rather, what appears is pure looking *green* (the complementary of the red of the long wavelength beam). As with Goethe's anecdotes, this experiment provided an example of *induced colour* for which the only plausible explanation is that colour is somehow made inside the head, perhaps in the eye or perhaps in the visual processing part of the brain.

Colour constancy

Taking these two phenomena together Monge was able to make the imaginative leap required to associate them with a third phenomenon, now known as "*colour constancy*", and even to go as far as producing a plausible explanation that was unequalled until the 1970s[2] and unsurpassed until the 1980s.[3] This required the involvement of the higher reaches of the brain and added important fuel to the growing conviction that colour is made in the head.

There is much more to say about *colour constancy* since it was to play a very important part both in the development of painting and in the evolution of the ideas about painting effects in due to *reflected-light* described in this book.[4]

The three primaries.

Another important figure in the story was Thomas Young. In 1810, about the same time as Goethe shared his observations and insights, he published a paper that updated Newton's ideas. A main part of his evidence was a demonstration using a set up, along the lines of the one illustrated *Figure 3*. What he showed was that the whole gamut of prismatic colours can be made by combining the outputs from three light sources, (namely a *red, green and blue*), which he named "*the three primaries*" . Amongst other things *Figure 3* shows is that neither the *primary* nor the *secondary* colours are the same for mixtures of light as they are

2 Land, E.H., 1979, "*The Retinex Theory of Colour Vision*". Scientific American.
3 Annie Hulbert, 1986, "*Formal connections between lightness algorithms*" Journal of the Optical Society of America A Vol. 3, page 1684 and "*What Scientists can Learn from Artists*", *Chapter 11*.
4 For explanation as to why see *Chapter 6.*

for the more widely known mixtures of coloured paints Perhaps most obvious are the case of:

- *Green,* which is a primary for light mixtures and a secondary for paint mixtures.
- *Yellow*, which is a primary for paint mixtures and a secondary for light mixtures.

Also important to notice is that each mixture is *brighter* than either of its parents:

- Blue and red make a much brighter *magenta.*
- Green and blue produce a much brighter *cyan.*
- Red and green produces a much brighter *yellow.*
- All three produces white which is the *brightest* of all.

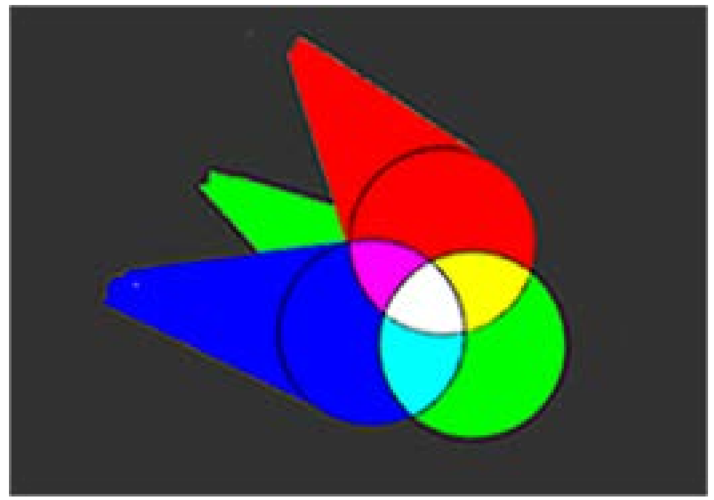

Figure 3 : The three light primaries (see also Figure 1, Chapter 8).

The reason for the increased brightness is that the energy of the combining light beams has been *added* together, explaining why the process is described as, "*additive colour mixing*". On the basis his findings Young postulated that:.

- In the back of the eye there must be three different receptor types (he described them as, "*Nerve fibres*") each of which is sensitive to a different part of the visible spectrum.
- All colour perception is mediated through these.

Here was a scientist not only realising that colour is made in the head but taking the tentative steps towards a *neurophysiological* explanation.

Colour contrast effects

In 1838 Michel Eugène Chevreul, a chemist who was employed to investigate the chemical properties of dyes at the Gobelin tapestry works, published a paper on one of his discoveries.[5]. He called it "*simultaneous colour contrast*" and encapsulated it in the rule that "*wherever two regions of colour have common border, the difference between them is exaggerated.*" Apart from giving artists exciting ideas in the domain of pictorial dynamics, his findings were important for providing yet another piece of the jigsaw which was, step by step, making it incontrovertibly clear that colour must be made in the head.[6]

By the time that the *First Impressionist Exhibition* in 1873, the idea that colour is made in the head had not only been widely accepted by scientists, but had also become fundamental to the thought of many artists, including the young *Impressionists*.

Going beyond colour

Amongst the most influential of the scientists building on the findings of Gaspard Monge, Thomas Young and other early researchers in the field of what later came to be called "*visual perception*" was Herman Helmholtz. This celebrated polymath, who was subsequently described as the "*Father of Psychophysics*",[7] published the third and last volume of his seminal work on the subject six years before the "*First Impressionist Exhibition*".[8] It was a *tour de force* in which, amongst many other things, he gave new impetus to Young's ideas on the *three primaries.*[9] Helmholtz also had much to say on other issues, including the subject of *colour constancy.* Although, in this case, his suggestion was vaguer and further from the mark than that of Monge, his proposals as a whole gave what was regarded as authoritative support to the idea that many of the mysteries of visual perception could be explained on the basis what he called "*unconscious cognitive*

5 Eugène Chevreul, 1838, *The Principles of Harmony and Contrast of Colours and their Applications in the Art*s, First English translation by Charles Martel, London 187

6 Much more will be said about simultaneous colour contrast in Chapter 21.

7 Now more commonly known as "*Psychology of Visual Perception*".

8 *Handbuch der Physiologischen Optik*: (Part 1 - 1856 Part 2 - 1860 and Part 3 - 1867)

9 To such an extent that the theory of the three primaries has since been called the *Young/Helmholtz theory*.

inference". Whether right or wrong about details, Helmholtz's more inclusive ideas were to have an enormous influence on scientists and artists alike. Amongst the latter was Cézanne, who is known to have shown interest in his publications.

Seurat and reflected light

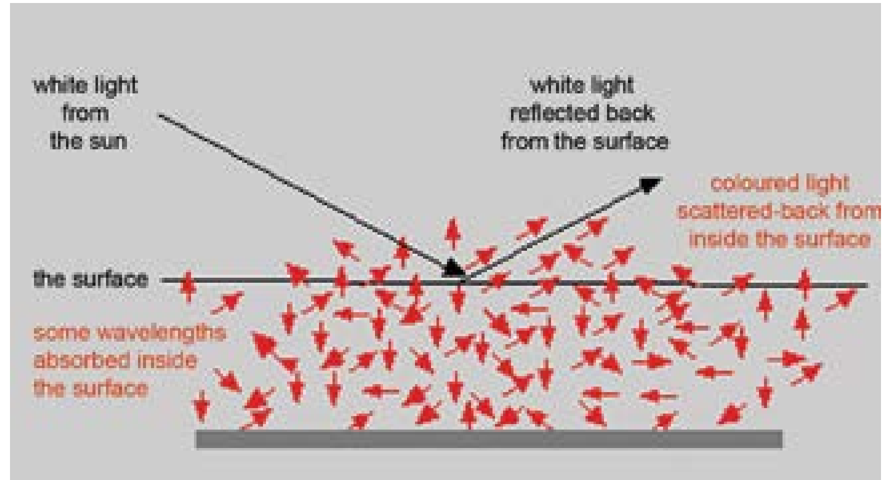

Figure 4 : Diagram of light being (1) 'scattered-back' and (2) 'directly-reflected' from a surface

At some time around 1880, Seurat saw a diagram in a science book. It not only changed the course of his own life, but also opened up revolutionary possibilities with respect to the use of colour in painting for everyone else. The diagram in question was analogous to the one in *Figure 4,* which shows that when light strikes a surface it interacts with it in two ways. Thus:

1. One part penetrates the surface. When inside, it interacts with the particles of pigment it encounters, such that some of its wavelengths are absorbed, while the remainder, having been scattered about inside the surface, are scattered back out of it. Since white light contains all the visible wavelengths, the wavelength composition of this scattered-back-out light is determined by the part of the spectrum that is not absorbed. It this that the eye/brain uses when constructing the characteristic colour appearances of the surface-types in question, for example, the "*reds*" of tomato, the "*greens*" of summer leaves, the "*yellows*" of daffodil flowers, the "*skin-colours*" of skin, etc. In this book this is called "***body-colour***".

2. The other part of the light never enters the surface but is reflected directly back from it, as if from a mirror or, rather, since actual surfaces are seldom mirror smooth, from a multitude of miniscule mirrors set at a multitude of different angles to the incoming light. The crucial point is that no wavelengths absorbed. Accordingly, the wavelength composition of the reflected light is the same as that of the light that strikes it in the first place. If the incident light is daylight, this means the light that enters the eye contains all visible wavelengths (see *Figure 1* and *Figure 2*). In this book it is this is called ***reflected light***.

With these ideas in his head, Seurat, realising that, if he were to create the desired effects of light in his paintings, he would need to find a way to represent the ***reflected-light***, he would need to use complex mixtures of coloured pigments to represent all the wavelengths contained in it. To work out how this might be done, Seurat turned to two other scientific sources. Firstly, to the ideas of Young and Helmholtz that led to the three primary theory, namely that all colours except the three primaries are mixed in the eye and, second, to the phenomenon of, "*Optical colour mixing*".

Optical colour mixing

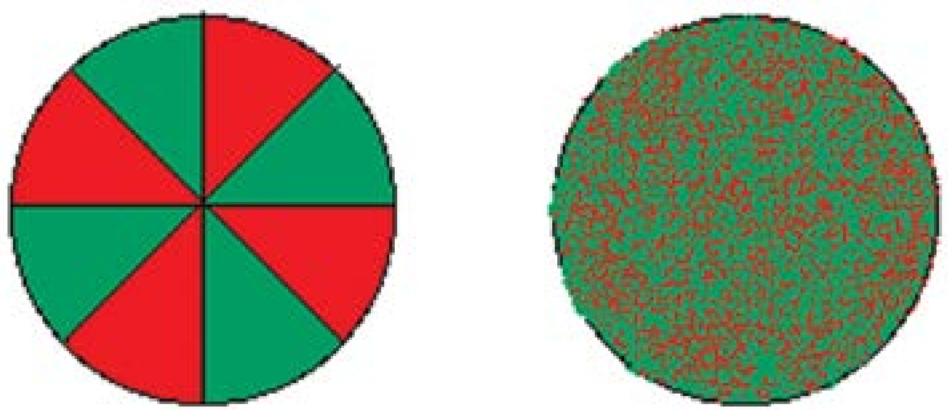

Figure 5: Discs representing different methods of optical colour mixing

He could have found out about optical colour mixing in Chevreul's book, but it seems that he was more influenced by the research of the physicist James Clerk Maxwell (known as the "*Father of Modern Physics*"), who demonstrated

experimentally a simple fact that proved to be of cardinal importance, not only to Seurat him but also for the future of painting.

Optical-mixing occurs when the eye cannot resolve differences between regions of colour on a surface which, as a result, blend into one impression. There are two main kinds of it. These are illustrated in *Figure 5* and can be classified as, "*Temporal*" and "*Spatial*". Thus:

- *Temporal optical colour-mixing* takes place if a multicoloured surface moves sufficiently fast that the eye can no longer distinguish the individual colours. The classical way of doing this was pioneered by James Clerk Maxwell, using fast-rotating discs similar to the one illustrated by the left hand side image in *Figure 5*.[10] If it is rotated fast enough, only one colour can be seen. To Seurat's delight, when the disc was divided into red and green (as illustrated) the one colour produced proved to be "*yellow*" (even if only a rather dull one). In other words, it turned out that colour mixtures arrived at in this way obeyed the rules of light mixtures rather than those of paint mixtures.
- *Spatial optical colour-mixing* results when regions of different colour on a surface are sufficiently small and closely-packed that, whereas from a near viewpoint they can be seen separately, from further away, they merge into one impression. The right hand side disc in *Figure 5* provides an example. Look at it from close and it will be seen as red dots on a green background (or visa versa), while from far it blends into one colour. Once again, it turned out that colour mixtures arrived at in this way obeyed the rules of light mixtures rather than those of paint mixtures.

In short, both temporal and spatial blending produced produce results that are governed by the additive mixing rules that apply to mixtures of coloured lights. Accordingly, in both cases,, "*red*" and "*green*" add together to make "*yellow*" and not the "*black*", "*grey*" or "*brown*" which they produce when red and green paint are mixed together.

Implications

All of the above mentioned discoveries of the scientists had an important impact on the artists. To find out what Seurat and his successors made of them we move on to the next chapters.

10 Maxwell, 1856, Transactions of the Royal Scottish Society of Arts 4, 394-400