CHAPTER 9

Seeing Light

Introductory

We have now completed our review of the historical background. It is now time to progress to more recent understandings. This chapter examines the meaning of the verb "to see". Some may wonder why this is necessary. After all "seeing" is something:

- *That we have done every day of our lives.*
- *With which we feel comfortable.*
- *Upon which we can virtually always rely.*

However, while it is hard to deny that we "see" colours, we should not be so confident about whether the word "see" is appropriate for our perception of the way light:

- *Transforms our perception of our visual world.*
- *Imbues surfaces with a sense of solidity.*
- *Enables us to experience objects as existing in a three-dimensional, light-filled space?*

The problem is that, as soon as we try to analyse the component parts of these potent aspects of visual experience, they dissolve in front of our eyes. A main reason why is that we can only look consciously at one thing at a time.[1]

SEEING LIGHT

So what do we mean by the phrase "*seeing light*"? As just suggested in the

1 *Appendix B and Appendix C treat of the issues raised by this ephemerality in greater detail and provide useful illustrations.*

Introductory, we do not experience light in the direct way that we experience colour, but in some other, more global and less easy to pin down manner. However the difficulty of arriving at descriptions does not diminish the importance of the experience we are trying to describe. How could it when, despite its invisibility, it provides us with properties of visual experience of such vital interest to artists, including: *"sense of surface*", *"intimations of three dimensional space*" and *"an awareness of the quality of light around us*".

The science [2]

Figure 1 : A multicoloured display

2 This section is a recapitulation of points made in the "*What the Scientists can Learn from the Artists*", in particular in *Chapters 11* and *12*. For the reader's convenience, *the first of these two chapters* is reproduced in *Appendix B,* where a number of illustrative diagrams will be found.

For a better understanding of how light can be both fundamental to visual experience yet be in a very real sense invisible, it is worth turning to a number of scientific findings relating to the subject of ***colour constancy***. In 1979, an article by Edwin Land was published in the *Scientific American*. It described a powerful demonstration of this phenomenon. A multicoloured display, along the lines of the one shown in *Figure 1,* made of different coloured papers glued to a flat rectangular surface[3] was illuminated by overlapping beams from three slide projectors. Each beam was a different light-primary so that all three together could be combined into one beam of achromatic white light. Each projector was controlled by a dimmer-switch so that the intensity of the each beam could be varied independently. Accordingly, the wavelength combination provided by the overlapping beams could be varied in an infinite number of ways to create millions of wavelength combinations. With this set-up Land demonstrated three things:

- If sequences of wavelength combinations are used to illuminate a screen of uniform colour (for example white), each change in the relative intensity of the projected light produces a different colour. The total number that can be reproduced is only limited by the sensitivity of the eye, which can discriminate between millions of them.
- If the same sequences of wavelength combinations are used to illuminate a multicoloured display, so long as all three beams are making some contribution to the illuminating light, none of the colours in it will change its appearance.
- If any one of the three beams illuminating the multicoloured display is switched off entirely, the colour appearance changes immediately.

The explanation as to how the presence of the three overlapping beams can ensure colour constancy can be related to the earlier discussion of how Seurat derived his ideas for painting "*light"*. As explained there, Seurat's starting point was the diagram that illustrates the important distinction between ***body-colour*** and ***reflected-light***.[4] At the University of Stirling we demonstrated the plausibility of the idea that the eye/brain is able to separate out these two components and make use of information contained in both. In particular the separation allows the eye/brain to:

3 Land called his version of this a "*Mondrian*" as it reminded him of one of the Dutch artist's paintings.
4 *Already illustrated both in the "Second Introduction: Some Preliminary Science"*, *Figure 1,* and *in Chapter 4, Figure 4.*

- Discount the presence of reflected-light when analysing body-colour. As a result, all regions of identical pigmentation are perceived as being the same. This phenomenon can be described as "*spatial colour constancy*".
- Use the information contained in the wavelength composition of the reflected-light to classify colours as the same even when perceived at different times and under different lighting conditions. The phrase used for describing this phenomena is "*temporal colour constancy.*"
- To compute the rate of change across the profile of the reflected-light. Sudden changes indicate the borders between: (a) different colours on the same surface,[5] (b) cast shadows and their relatively lighter surrounds; and, (c) a surface and surfaces situated either behind or in front of it. Slower rates of change indicate ***surface-form*** and the slowest provide a sense of ***surface solidity***.

Luckily for us, there is a systematic in error in the way the ***eye/brain*** interprets the sudden changes in the level of lightness that occur at the borders of ***cast shadows***. The reason for it is that ***eye/brain systems*** cannot distinguish these sudden changes in the level lightness from the sudden changes in the level of lightness that occur at the borders of ***body colours***. As a result, regions of ***shadow*** are wrongly classified as regions of ***body-colour***. This is lucky for us because, if this was not the case, we would not ***cast shadows*** would be invisible to us. As it is, they classify ***regions of shadow*** as ***regions of body-colour*** and, because they are regions of relatively low reflectivity, we see them as tending towards "***black***". In an analogous way the eye/brain interprets more subtle increments in lightness as the graduated greys that are characteristic of ***shading***.

Significantly for those of us who are faced with the challenge of painting shadows, the fact that we remain unaware of the residual, multiple wavelength reflected-light coming from the shadowed region does not mean that it should not be represented. On the contrary, it is very important to do so as it is these that gives shadows a sense of laying on a surface, as opposed to being perceived as holes in it. We shall see later how this applies when making paintings.

The eye/brain systems are similarly confounded by ***highlights***, which it also classifies as ***body-colour***. They make exactly the opposite interpretation of the sudden dips in lightness that they interpret as shadows. Accordingly, the sudden jumps in lightness that occur at their borders are seen as tending towards white.

5 Such as those between the colours in the multicoloured display shown in *Figure 1.*

A paradox resolved

As explained in *Chapter 1*, Professor Bohusz-Szyszko used the physics of inter-reflecting secondary light sources to explain why no two surfaces or no two separated regions of any one surface, even though identical with respect to their pigment-colour, can be reflecting the same wavelength profile. He further asserted that any repetition of the same pigment-colour in two or more regions of a painting will always have a disturbing effect. As I explained in *Chapter 2,* where I gave consideration to this proposition, I found myself faced with what seemed to be a paradox. Clearly the physics-based rule that no two regions of any surface can ever reflect quite the same wavelength combinations of light must apply to separate regions of pigment-colour painted on a picture surface. In which case, how can they be perceived as being the same? And if they can only be perceived as different, how can their presumably nonexistent sameness have the destructive effects on the experience of looking at paintings claimed by the Professor and confirmed by my own observations?

All these questions and, consequently, the paradox are easy to resolve once account has been taken of the existence of visual systems that separate out body-colour and surface-reflection. The two patches of identical pigment-colour look the same because one of these systems has removed the influence the reflected-light on what we see. Once this has been done all that is left to see is the similarity of pigmentation.

As indicated above, this transformation of slightly different wavelength combinations into identical colours is known as "*spatial colour constancy*"

Seeing the invisible

Earlier I explained that the separation of ***reflected-light*** from ***body-colour*** enables the ***eye/brain*** to disambiguate the information available in each of the two modalities. However, it is clear that both of them cannot be visible in the same way, at the same time. This being the case, the fact of our being consciously aware of ***body-colours*** precludes the possibility that we can experience ***reflected-light*** in an analogous manner.[6] Does that mean that the ***reflected-light*** is invisible? If so, how is it that we can we make use of it? Two experiments with damaged visual systems and some speculations on how the eye/brain makes sense of

6 Except in the special case of ***cast shadows, shading*** and ***highlights*** which, as explained earlier, are made visible as a result of an eye/brain systems computing error.

the light borne information coming into our eyes help us to approach answers to these questions.

Two experiments

The two experiments concern the phenomena which are due to damage to the ***retina*** and to the ***parietal lobe*** in the ***visual area of the brain*** respectively:

1. The first of these, due to damage to the ***retina,*** is known as "***blind-sight***". Studies involving patients suffering from this condition demonstrate that they can point at targets of which they are not consciously aware. The explanation for this surprising capacity is that the ***superior colliculus***, the part of the eye/brain which controls pointing and eye-movements, operates via neural pathways which bypass the ***visual area*** of the brain where conscious vision is generated. Accordingly, the studies show that conscious awareness is *not* necessary either for pointing at a target or for directing the eyes towards it.
2. The phenomena due to damage in the ***parietal lobe***, situated in the ***visual area of the brain*** is known as "***unilateral-neglect***". Patients suffering from it are unable to see half of their visual world. Two Italian psychologists gave a variety of tests to people suffering from this demi-blindness.[7] Their findings are extremely interesting for many reasons. From the perspective of this book, the most significant part of them is the evidence that:
   - The ***conscious*** analysis of an object can only takes place ***after*** is has been ***recognised*** by means of ***preconscious*** processes using a pathway that operate independently of the parietal lobe.
   - People always "*know*" what they are looking at before they are consciously aware of it.

Some speculations

The speculations on the nature of the ***preconscious processes*** that enable ***recognition*** were central to our work at the university of Stirling.[8] They were based on the known power of mathematical principles relating to cross-correlations between independently varying modalities of information. They propose that:

- ***Independently operating*** eye/brain subsystems break up all visually derived information into a number of different ***abstractions*** (ways of organising information), including ones derived separately from both reflected-light profiles and body-colours.
- The essential property of the abstractions is that each of them can be produced by a range of different inputs. In other words, each is a vague generalisation.
- ***Cross-correlation*** between the vague generalisations generated by different eye/brain systems[9] provides the basis for ***recognition.***

The vagueness of the abstractions provides a necessary part of the solution to one of the most fundamental problems that the processes of evolution had to solve if objects were to be ***recognised***, namely that of being able to classify inputs as the ***same*** under a variety of viewing conditions that ensures that they are always ***different***.

What artists need to learn from all this is that, while the nature of these neurally generated abstractions is a matter for speculation, the fact that they are necessary for visual perception is not. Nor is the fact that none of them could ever be described in terms of a conscious visual experience.

This leaves the artists with the problem of how to recreate the visible consequences of these invisible properties of visual experience in paintings. Since there is no serious alternative to using coloured pigment to conjure them up in the eye of the beholder, the question arises how best to do this. What follows in this chapter and the next provides the theory that gives context to the practical solutions offered in *PART 4*.

ANALYSING THE INVISIBLE

Focusing down

If the concept of *seeing* the invisible poses problems, what about the issue of *analysing* it? Is it possible to analyse something that we cannot see? In order to approach an answer to this question, it helps to refer to a second demonstration by Edwin Land, in which *colour-constancy* is destroyed when the beam of light

7 Bisiach, E. and Luzzatti, C., 1978, unilateral-neglect and the representation of space. Cortex. Vol. 14, pps. 129-133

8 Particularly important in formulating these was Dr. Alistair Watson.

9 As well as other systems dealing with other modes of sensory input.

is focused-down, by means of a diaphragm[10] exclusively onto a small, monochromatic region of the multicoloured display.[11] With the contextual influence of the surrounding colours removed, it is the *wavelength combination* of the light-beam that determines the colours we see. Accordingly when a patch of red body-colour is isolated from its context it can be made a range of different colours, including grey, by manipulating the relative strength of the three light beams to give prominence to the complementaries of red. However, when the diaphragm is opened up and the contextual influence restored, the same patch of colour, illuminated by the same wavelength combination is perceived as red.

From this experiment we see that limiting the area of focus to a region of uniform pigment-colour can render the context-dependent, colour-constancy system inoperative and, accordingly, make visible the hitherto invisible reflected-light.

So how does this help artists?

Comparative looking

The answer lies with the use of ***comparative looking***, a procedure that involves moving the focus of the eyes from one place to another and isolating small regions of surface and making ***comparisons*** between them, using ***same/different judgements***. The problem arises that, if the body-colour of the compared regions is the same, then the only difference between them will be in their reflected-light profiles. But according to what I have been asserting, their ***reflected-light*** profiles will be invisible. If so, how can artists, or anyone else, see this difference? Clearly nobody could see it unless the reflected-light were to be made visible.

But this is just what Land's demonstration accomplished by isolating regions of colour from their context, which is exactly what ***comparative-looking*** does. The big difference is that the colours as viewed under the different conditions in Land's demonstration can be kept stable as long as the experimenter wishes, which is not the case with comparative looking. Immediately after the comparison has been made, the influence of context is restored and influence of the reflected-light on appearances evaporates.

What we see

But what does this mean in terms of what we actually see? It means that:

10 Similar to those that control the amount of light entering the lenses of cameras.

11 For fuller explanation with diagrams of Land's second demonstration see *Appendix B*.

- When analysed independently, the two patches of identical body-colour will be perceived as being the same,
- When analysed comparatively, the existence of a difference will nearly always become evident.

But how can these differences be described? Whatever words are used, they will always include two priceless bits of information:

- The *direction* of change.
- The *degree* of change.

The direction of change can be indicated by using words relating to the five variables of colour perception, namely *hue, saturation, lightness* and *texture*, with its subdivision into shininess and graininess. Thus, for example, one of the compared patches might be described as *"redder", "darker", "greyer", "shinier*" and *"less grainy*" than the other. The degree of change can be characterised by employing phrases on the continuum from "*scarcely perceptible*" to "*very easy to see*".

Such descriptions of relativities between the basic colour variables and degrees of change are all the artist needs, even though no combination of words or phrases can adequately do justice to the astonishing sensitivity to nuance of the human visual system. As already indicated, one estimate suggests that the eye/brain has a capacity for distinguishing up to about *seven million* different colours.[12] Whether this is accurate or not, it gives an idea of the huge range that underpins our potential for experiencing colour differences in nature, including those due to variations in reflected-light profiles.

From the practical point of view, the good news is that, once introduced to the idea, it becomes easier and easier to detect smaller and smaller differences and there is nothing to stop more or less everyone learning to see the subtle modulations across surfaces and between regions of identical body-colour that so fascinated Cézanne. Indeed, in view of his poor eyesight and refusal to wear spectacles, most people should easily be able to outperform the *Master of Aix*.

Even better news is that because pioneers like Leonardo da Vinci and Cézanne have shown the way, their successors start with the advantage of knowing what to look for and how to set about finding it. There is no longer any need to replicate the heroic struggles of the pioneers.

12 Another estimate suggests a mere 2.5 million.

Residual difficulties

However progress is not always easy. Sometimes:

- The ever present difference between two regions of identical pigmentation as modified by different wavelength combinations of reflected-light is so small that it cannot be detected by comparative looking, even though it is large enough to play a part in the subconscious eye/brain processing that tells us about surface, space and light.
- The same degree of difference that can be detected between neighbouring colours will not be detectable between widely separated ones. One reason for this can be that detecting differences requires the uninterrupted overlaying of the inputs being compared, and large eye movements are likely to be produce interruptions.
- Quite large differences in reflectivity are obscured by the operation of eye/brains's visual systems, as is the case with detecting differences between regions within ***cast shadows.*** The next section explains why.

Cast-shadows[13]

Figure 2: Shadows cast by a fence

13 For much more on this subject see **"***Painting with Colour***",** *PART 4, "Chiaroscuro."*

Figure 1 represents three fence posts casting their shadows on a flat surface. Outside the shaded regions this surface is illuminated by sunlight, inside them, by a combination of much less powerful secondary light sources. The difference in lightness is both abrupt and dramatic. Since the eye/brain cannot distinguish between sudden jumps of lightness of this kind and ones that occur at the border between different body-colours, it perceives the shadows as *body-colour*.[14] The experiential consequence is that all normal-sighted people see cast-shadows as the pigment-colour of the surface upon which they fall, drained to a greater or lesser extent of the hue element. In other words, as a slightly coloured "*dark grey*" or "*black*".[15]

But does eye/brain system computing error mean that part of the reflected-light profile that provides us with a sense of surface will overlooked? The answer is "*no*", for no matter how large the step down in the luminosity at the border between the shadow and its sun-illuminated context, there will always be a residual slow-varying portion of reflected-light that will not be taken to be body-colour and this will always be interpreted in the same way as the residual slow-varying gradation relating to any other surface. In other words, it will provide a perception of ***surface solidity***. If this were not the case, shadows in the real world would look like the seemingly surfaceless holes that the ***Impressionists*** saw in their academic predecessors' depictions of shadows in their chiaroscuro paintings. One of Seurat's achievements was to provide a method of providing the missing solidity.

Misleading ideas about shadow painting

Seurat's colour-based method of representation the residual, the part of the reflected-light profile coming from cast shadows that indicates surface-solidity should not be confused with the violets and blues, which art teachers and the authors of how-to-do-it books on painting encourage their readers to see. Like so many of their ideas, these originated with the ***Impressionists***, who in their turn were influenced by the findings of scientists relating to ***induced violet*** (the complementary of the yellow in incandescent light sources) and the predominance of the shorter wavelengths in the light scattered back to earth from blue skies. What the teachers fail to consider is that these phenomena are rarely visible in real world situations: Even when they are a part of the mix, other factors are likely to

14 Fully worked out in *"What Scientists can Learn from Artists" Chapters 12*

15 Except under certain exceptional circumstances which will be detailed in "*Painting with Colour*".

be far more important in determining appearances. This oversight would not matter very much, if it were not for its negative consequences. Naturally the students strain every nerve to see the purples and blues that they are told exist and, if, as is very likely to be the case, they fail, they cannot be blamed for coming to one of two erroneous conclusions that might lead them to despair of becoming artists: Either their vision must be deficient or their artists teachers have unattainably "special eyes". But they would be wrong to do so. Studies of the capacities of the eye/brain' should reassure anyone who comes to such self-belittling conclusions. Research into the sensitivity of the eyes and the demonstration by Edwin Land described at the outset of this chapter between them show that:

- The range of colours that each of us is capable of seeing is essentially the same as the range available to everyone else.[16]
- None of us has special eyes for seeing induced violets or sky-reflecting blues in shadows. If we see them, so can everyone else, and, if we cannot see them, nor can anyone else.

In the vast majority of cases, neither colour is visible in shadows. Perhaps we can learn from the analysis of shadows in at paintings made before:

- The coming of the nineteenth century revolution in the science of visual perception (described in *Chapter 5)*.
- The adoption by the Impressionists of their ideas about induced and simultaneously contrasting colours (described in *Chapter 6)*.
- The arrival of the science-based ideas of Seurat (described in the previous chapter).

In these, we see no sign of purples, blues or mosaics of complementary colours. It looks as if the artists who painted them saw cast shadows as the colour of the surface upon which they fall, modified more or less strongly in the direction of grey or black. I believe that, if we are honest with ourselves, this is also what all the rest of us see.[17]

If, as artists, we wish to add colour to shadows in our paintings, we are free to do so, not because we see them but because doing so improves the painting in some way. For example, if it provides them with a sense of surface.

16 As long as we have either have normal focussing capacity or are wearing spectacles that correct for any shortcoming in this respect.
17 Unless they have anomalous colour vision, often referred to as "*colour-blindness*".

Pure body colour

Figures 3, 4 and 5 : Examples of nearly pure body-colour.

As illustrated diagrammatically in *Chapter 5, Figure 1*, the colour we see when we look at a clear blue sky is due to the light of the sun being scattered by particles in the atmosphere, with the shorter wavelengths being scattered a great deal more than the longer ones. It is no coincidence that this description has much in common with the one used at the beginning of the book to describe the light that enters a surface, interacts with the particles it finds in its path and, having been scattered around inside, is scattered-back out again to give "*body-colour*".[18] The big difference between the two is that our perception of the body-colour of surfaces is normally complicated by the presence of the reflected-light.

Does this mean that the way we perceive the blue of the sky (*Figure 3*) is equivalent to how we would see the ***body-colour*** of a surface, if only we could discount the influence of ***surface-reflection***? *Figures 4 and 5* illustrate two examples of ***transmitted light*** that provoke the same question.[19] In these, it is the light that emerges from our side of the glass or the petal that determines nature of the colours we see. After entering the surface from the other side, it has been partially absorbed and partially scattered around inside by the pigment particles it encounters, before the unabsorbed wavelengths have been scattered out on the other side and into our eyes. As we all know that there is something special about the resultant colours. There is a purity, a surfacelessness, a depth and a mystery to them, which makes them quite different from the colours of surfaces that are perceived from the same side as the light source,[20] and that qualifies them for classification as ***pure body-colour***.

Another example of surfaces that have no reflective properties are television and computer screens. Since we see them solely by light emitted from their phosphors and since there is no reflected light to complicate matters, they can be described as providing ***pure body-colour***. This is a major reason why images displayed on these types of screen are so different from and so much better than photographic prints with respect to the way they reproduce transmitted light.[21]

18 See *"Introduction to the Science")*
19 Though there must be some light reflected from the surfaces that face us, it is in negligible quantities.
20 Including printed images of the sky, stained glass windows and light transmitted through petals such as those featured in *Figures 3, 4 and 5*. The reason for this difference is that printed images lie on a surfaces from which slow-varying modulations of light are scattered back into our eyes with the result that the sense of *bottomless-depth* to be found in actually transmitted light is destroyed..
21 Their shortcoming lies in the way they reproduce body-colour/reflected light combinations.

Pure reflected light

Figure 6 : Pure reflected light

Pure ***reflected-light*** is almost as rare in the natural world as pure ***body-colour.*** It can only exist where there are absolutely no traces of body-colour emerging from the surface from which it is being reflected. The reflections in the water in *Figure 6* provide a number of examples of this rare possibility. Another would be all pure white surfaces.

Depicting body-colour/reflected light combinations

When analysing the appearance of coloured regions of surfaces with a view depicting them, it is worth remembering that:

- The ***reflected-light*** component of the light coming them invariably consists of a jumble of all the wavelengths of light.
- All the wavelengths mixed together make white.

It is for this reason that the presence of ***reflected-light*** will tend to whiten (desaturate) the appearance of the ***body-colour*** with which it is being compounded. The degree of this tendency will depend on two factors. The first of these is obvious, the second less so. They are:

- The proportions of body-colour and reflected-light entering the eyes.
- The extent to which the reflected-light is taken off by the eye/brain's colour-constancy system.[22]

Factors that will influence the latter are:

- The *degree of glossiness* and the *texture profile* of the surface.
- The triangular relationship between the *viewing position, the surface* and the *light sources* illuminating it.

Fortunately, it is not necessary for artists to struggle with the impossible task of working out the relative influence of these factors. No matter how numerous the contributing variables or how subtle the effects they produce, the outcome in terms of colour appearance can be summed up succinctly: The less visible the scattered-back, reflected-light, the nearer the regions of colour being viewed will be to having the appearance of **pure body-colour.** The only way of finding the point of least reflectivity is by experimenting with viewing angles, but the best outcome will involve looking at the surface from a position where the angle between the predominant light source, the surface being viewed and the eyes is less than 90°.

Implications

This chapter has focused on many issues of great significance to painters. In particular they concern aspects of appearances that are not available for conscious analysis. These relate to those parts of the reflected-light that the eye/brain's visual-systems has rendered invisible. Luckily, despite not being able to see these directly, we can find out something about their presence by means of comparative looking. However, even this does not always work. In some cases

22 "*What Scientist can Learn from Artists", Chapter 14.*

the difference between the compared regions is too small to be available to conscious analysis. Even when comparisons enable us to detect a difference, we will unable to analyse the reflected-light because its separation from the body colour/reflected light mixture depends on contextual information that is lost if ever we focus down on what we are looking at.

The information presented in this chapter should make it clear that the only way for artists to represent any of these much sought after properties of appearance satisfactorily is to base their efforts at least partly on theory. Luckily, as has been explained above and in previous chapters the relevant theory is now available in a succinct and reliable form that is easy to implement. Thus:

- *Seurat led the way in this respect by means of his science-based approach to painting light.*
- *Cézanne extended the potential of Seurat's ideas through his research into whole-field colour relations.*
- *Professor Bohusz-Szyszko formalised the joint findings of his two predecessors in a thought-provoking synthesis encapsulated in his dogmas.*
- *Research done at the University of Stirling explained the power and limitations of his pronouncements and, in doing so, offered a comprehensive theory that further facilitates the Professor's already easy to follow practical suggestions for artists.*