2475 3835

ERRATA

P 26,line 22: " prima-facie" for "prima facie"
P 26 line 22: "object's" for " objects"
P 35 line 3: "....." for "...."
P 35 line 13: " *natural* " for " natural "
P 42 line 11: " process" for "proces s"
P 65 line 12: "error " for "srror "
P 71 line 7: "yield" for " yeild "
P 80 line 14: " a neo-Lockean " for " an neo-Lockean "
P 82 line15: " (p.267) " for " (p.267)[9] "
P 83 line 7: " them." For " them "
P 83 line 8: " I will " for " . I will "
P 87: line 23: " tout-court " for " tout_court "
P 89 line 2: " conjecture " for " conjectur e "
P 94 line 19: remove " [my emphasis] "
P 97 line 26: " don't " for " dont "
P 98 line 15: " to carry out that " for " to that "
P 101 line 28: " he argues " for " he argue "
P 106 line 12: " Moorean " for " Mooream "
P 105 line 19: " are true " for " are true to true "
P 108 line 19: "us " for " us" "
P 112 line 5: " circuitry " for " cicuitry "
P 117 line 29: " of physical " for " of of physical "
P 139 line 25: " eventually to " for " eventuallto "
P 161 line 16: " anomalous " for " anomolous "
P 163 line 19: " light " for " light " "
P 169 line 15: "don't " for " dont "
P 187 line 10: "stimuli, " for : " stimuli. "
P 191 line 28: "How " for " how "
P 198 line 24 " qualities " for " qualitiess "
P 204 line 8: "this. " for " this "
P 205 line 25: "natural " for " narural "
P 228 lines 4 & 5: remove "[my emphasis] "
P 245 line 14: "In " for " ". In "
P 268 line 5: " John Wiley & Sons " for " John "

AN ANALYSIS OF COLOUR AS AN OBJECTIVE PROPERTY OF OBJECTS IN THE WORLD.

W. R. WEBSTER

DEPARTMENT of PHILOSOPHY, MONASH UNIVERSITY.

BA (HONS I), 1962; PhD (1969), UNIVERSITY of SYDNEY

Submitted for the Degree of PhD at Monash University

On 21st November, 2001

TABLE of CONTENTS

Table of Figures

ABSTRACT

In this thesis, I address what has been described as the central problem of colour, i.e. whether colour is a physical property or whether it is mental property. In the first few chapters, I look at criticisms of realist theories of colour; these criticisms lead to a subjective account of colour. I show that these criticisms are largely based on visual phenomena such as: metamers, opponent colour processes, unique and binary hues, simultaneous colour contrast, and colour constancy. I present evidence that metamers don't occur in nature, certainly not in the conditions under which human colour vision evolved. I discuss the evolution of human colour vision in the context of a theory of Mollon (2000), which asserts that primate colour vision evolved in the forests, without I claim, any metamers being present. This suggests that disjunctive physicalist theories are not needed for human colour vision. I discuss an important dispositional account of colour based on Martin and Heil (1998), but I prefer Jackson's (1996) theory that colour is the categorical basis of the disposition.

I present evidence that arguments based on opponent processing are not as supportive of subjectivism as has been argued by Hardin (1988). This evidence shows that opponent processes are not the only mechanisms of colour, and thus a relationship can be provided between external colours and brain processes. I then give a topic neutral account of cases of so called illusory colours. I then argue that colour could be based on photon energy/ wavelength (PE/W) mechanisms. I base this largely on the work of Nassau (1983) and Maloney (1986). These mechanisms are based on a number of quantum effects, but mostly of photons of specific energies interacting with electrons of biological and non-biological material. These quantum effects lead to broad spectra of wavelengths being reflected from most natural objects. These spectra have none of the multiple peaks seen with metamers.

I examine other objective theories of colour and show that they also largely depend on the colour phenomena I have examined. I argue that they do not

give an adequate account of colour, because of their dependence on these colour phenomena.

I then look at a number of subjective theories and their objections to any primary quality view of colour such as those proposed by Jackson (1996) and Armstrong (1968). I conclude that they are not as adequate account of colour as my PE/W theory. I examine Levine's (1983) concept of the explanatory gap and its relationship with qualia. I demonstrate that the explanatory gap can be overcome in the case of after-images (AI's). I propose a mind/body identity account can be given for the first time with my account of AI's.

I look at representational accounts of consciousness and qualia, with particular emphasis on the work of Tye (1996a) and the arguments of Armstrong. I conclude that Tye's PANIC theory does not meet earlier criticisms of representationalism, but I support Armstrong's (1979) views about representations and beliefs and the causal relationships undermining the concepts of qualia and sense data. I examine Block's (1999a) arguments against representationism based on inverted and shifted spectra. I present evidence against these views.

I look at theories of colour put forward by Maund (1994) and Landesman (1989,1993). These theories argue that there are no colours in the world. I conclude that neither gives an adequate account of colour.

I then examine revelation and transparency in relation to colour. I argue that psychophysical research of Webster et al., (1992) shows that these concepts are not important for colour. I suggest that this psychophysical work is another way of overcoming the explanatory gap and is another possible case of a mind/brain identity.

Finally, I propose a speculative account arguing that the perceptions of colour are located in the infero-temporal regions of the human brain and suggest that this could be another mind/brain identity account. My overall conclusion is that it is possible to give a primary quality account of colour like that proposed by Jackson (1996) and Armstrong (1987), but with a PE/W mechanism rather than a simple wavelength account or Land's (1977) retinex mechanism.

SIGNED STATEMENT

This is a signed statement to the effect that the thesis, except with the committee's approval contains no material which has been accepted for the award of any other degree or diploma in any university or other institution and that

•affirms that to the best of the candidate's knowledge, the thesis contains no material published or written by any other person, except where due reference is made in the text of the thesis.

• three journal papers have been accepted, based on material in the thesis:

(1) a paper entitled " A case of mind/brain identity: one small bridge for the explanatory gap", SYNTHESE, 2002, (in press). This paper is based on material in Chapter 13.0 of the thesis.

(2) A paper entitled "Wavelength theory of colour strikes back: the return of the physical ", SYNTHESE, 2002, (in press). This paper is based on material in Chapters 1.0 to 9.0.

(3) A paper entitled " Revelation and transparency in colour vision refuted: a case of mind/brain identity and another bridge over the explanatory gap"

SYNTHESE, 2002, (in press). This paper is based on material in Chapter 16.0.

[redacted]

W. R. Webster

ACKNOWLEDGMENTS

I would like to acknowledge the encouragement and support of John Bigelow and Frank Jackson during their supervision. I also appreciate the kindness of Ian Gold for commenting on earlier drafts of the thesis. Finally, I thank my wife, Tessa Barrett, for her love and support.

CHAPTER 1.0

1.1 General Introduction.

The theoretical analysis of the concept of colour has undergone a considerable philosophical revival in recent years and has produced a voluminous literature, highlighted by the publication of a number of books on the philosophy of colour (Westphal, 1987; Hilbert, 1987;Hardin,1988; Harrison, 1989; Landesman,1989; Maund,1994; Thompson,1995; Byrne & Hilbert,1997 a, b; Davis, 2000; Stroud, 2000; Tye, 2000), which can be compared with their almost complete absence in earlier years . One of the main issues about the concept of colour is whether colour is a physical property of things in the world around us or whether it is a mental property which is not present in the external world. This has been described by Ian Gold (1998) as the central problem of colour. It came as a complete surprise to me, as a person who has carried out empirical research with colour, to discover that most research workers in the neuroscience field of colour believed a scientific version of the latter proposition. My surprise might have been due to my having been influenced in my undergraduate years by John Anderson (1962) and his pupil David Amstrong (1968) towards a realist approach to sensations and the mind.

Colour scientists are quite specific about their views on colour and I shall highlight them by a number of quotations. W. D. Wright (1959) in an article on the unsolved problems of colour vision comments that:

> I rarely stop to think that the redness of a pillar box is not an intrinsic part of the pillar box but is subjective within us. The constancy of the colour of things around us is in fact a remarkable tribute to the manner in which our visual sensations are mentally projected into the objective world. (p. 447).

Walls (1942) states that:

color or better ,"hue", exists only in the mind. No light or object in nature has hue, rather, the quality of hue aroused as a sensation is projected back to the object as one of its attributes, just as the patterns of brightness and darkness in consciousness are projected back into the visual field to endow objects with their size, shape, tone values and movement. For, I perceive objects rather than lights. I can see objects falsely as to size, shape, and motion, and just as falsely as to color since color is purely subjective (p. 81).

Gouras (1991) argues that:

> Our visual cortex essentially creates and interprets conscious reality, establishing an order and logic to our thoughts and actions. Colour vision is just one manifestation of the abstractions it creates in this case out of a colourless physical world (p.179) and that:

> understanding colour vision amounts to understanding how the nervous system transforms the information contained in electromagnetic radiation- which is itself colourless- into the colours which enrich immeasurably our visual environment (Gouras, 1990, p. 11) .

Zeki (1983) states that:

> The nervous system, rather than analyse colours, takes what information there is in the external environment, namely, the reflectance of different surfaces for different wavelengths of light, and transforms that information to construct colours using its own algorithms to do so. In other words it constructs something which is a property of the brain, not the world outside (p. 764).

Martinez-Uriegas (1994) states that:

> more precisely, color is one of the many representations of the environment constructed by the brain processes that comprise the visual system (p. 117).

A group of famous visual scientists (Zrenner, Abramov, Akita, Livingstone & Valberg, 1990) state that:

> Color exists only within neural networks that mediate perception. The outer physical world provides a mixture of light quanta, the energy and frequency of which have little resemblance to colors perceived (p. 163).

One might argue that perhaps all these scientists lack some training in philosophy but a large number of philosophers take a similar view (Hardin, 1988; Boghossian and Velleman,1989, 1991; Campbell,1993; Gold,1993; Lund,1994; McGilvray,1994; Tolliver,1994; Dedrick,1995; Maund,1995; Clark, 1996; Hall, 1996). Hardin (1991), for example, states that:

> If I take an experience of X to be Illusory in case there is no appropriate X to which experience corresponds, I would claim that whereas some of our visual and tactile shapes are illusory, all of our chromatic experiences are illusory ....there is no physical structure causally relevant to color perception that corresponds to the quality structure of chromatic experience (p. 79-81).

Boghossian and Velleman (1989) state that:

> the most plausible hypothesis about what someone means when he calls something red, in an every day context, is that he is reporting what his eyes tell him. And according to our account, what his eyes tell him is that the thing has a particular visual quality, a quality that does not actually inhere in external objects but is a quality of his visual field. We therefore conclude that when someone calls something red, in an everyday context, he is asserting a falsehood. Indeed, our account of colour experience, when joined with the plausible hypothesis that colour discourse reports the content of colour experience, yields the consequence that all statements attributing colours to external objects are false. (p. 100)

Both these scientists and these philosophers are taking a strong subjectivist view of the colour of objects but some philosophers think that this general phenomenal view has important and unfortunate consequences . For example, Armstrong (1968) thinks that this view would undermine any physicalist programme in that:

> to accept the view that secondary qualities (such as colour) are irreducible qualia of mental items would be to abandon the whole programme of this work (p. 272).

Lycan (1990) also argues that:

> for if there are phenomenal individuals, it follows immediately that materialism is false (p.115).

Thus it would appear that the exact nature of colour will have important ramifications for the ontology of the world.

CHAPTER 2.0

2.1 Realism about colour

Realism about colour has been part of the "Australian" view that colours are physical properties of objects, i.e. they are primary qualities (Armstrong, 1968; Smart, 1961, 1975; Jackson and Pargetter, 1987; Jackson, 1996). Most of the other group of philosophers[1], cited above, as having subjective views about colour, have argued that colour science does not support realism about colour, since visual phenomena such as metamers, opponent colour processes, unique and binary hues, retinex theory and colour constancy, and simultaneous contrast mechanisms, could not be reconciled with colour being a physical property such as wavelength. The main aim of this thesis is to demonstrate that these objections to realism are not as powerful as they once appeared.

Campbell (1993), in an important paper, has examined the different types of realism about colour in discussing Armstrong's views about colour realism. Campbell has strongly emphasized the critical relationships between the above colour phenomena and realism. Campbell points out that the response of Australian realists to these difficulties is to adopt some form of disjunctive realism as their basis for colour (Smart, 1975; Armstrong, 1987; Jackson and Pargetter, 1987; Jackson, 1996).

2.2 Disjunctive Realism and Dispositions

Smart (1961) originally proposed a position about colour close to Locke's (1690) dispositional approach to secondary qualities, but whereas Locke identified them with powers to produce ideas in us, Smart replaced mental ideas with behavioural capacities to discriminate. However, Smart remained a realist as he located colour at the objective end of this causal process. In Smart (1975), he adopted David Lewis's suggestion that a disjunctive account should be given for this external process, i.e. for objects with the same green colour, the relevant physical properties could be different. Campbell (1993) points out that Armstrong (1987) and Jackson and Pargetter (1987) expanded this dispositional approach by identifying colour with the categorical basis of the disposition.[2] Campbell (1993) argues that:

> The merit of opting for the categorical basis over the disposition which it is the basis...... is that dispositions are inferred whereas colours are perceived......On the Armstrong-Jackson-Pargetter theory, as for Smart, colour is in one sense indeed a secondary quality. For ' the fundamental ground for ascribing colour to something is the colour it looks to have ' (Jackson and Pargetter, 1987, p 131). Such essential reference to how things seem is never required for the ascription of any genuinely primary quality (p.258).

Jackson (1996), in a more recent paper, expands the approach of Jackson and Pargetter (1987), and emphasizes that he does not agree with any secondary quality interpretation. He argues that:

> Although colors presenr themselves in visual experience in a peculiarly conspicuous way, we do not use 'red' as the name of the experience itself, but rather of the property of the object putatively experienced when it looks red. For we examine objects to determine their color; we do not introspect. We look out, not in. ......In sum, the way we arrive at judgments about an object's color has the distinctive hallmarks of the way we arrive at judgments about the nature of the world around us. We have, accordingly, to see judgments of color as judgments about the nature of objects around us. (p. 200).

Armstrong (1987) argues that that he does not belong with Jackson and Pargetter (1987) as Campbell asserts. He says:

> Jackson and Pargetter, however, as I understand them, are influenced by specific difficulties about colour; further, they think of colour sensation as a physical process in the brain. (it is my impression that most contemporary Physicalists hold to some form of this 'Lockean' theory). I reject such theories..... It seems to me that I am pretty well compelled

(though not unwillingly) to take this position because of my theory of what sensations are. I hold that to have a red sensation is to acquire information (the term is meant to cover misinformation) that there is something red at some more or less specific place in the perceiver's environment......This account of sensation is propositional. (p. 270).

I support the argument that sensations should be regarded as propositional. That is, they should be given a belief account. However, I think Armstrong is not quite right about Jackson and Pargetter about sensations. The above quotation from Jackson clearly asserts that we look out not in. We make judgments about the colours of objects around us. We don't analyse sensations. The notion of a judgment is in keeping with a propositional account of colour. Jackson in a personal communication says that their views on colour are very close to those of Armstrong on this matter.

Jackson does say that his account does perhaps differ from Armstrong because:

> Although the theory identifies colors with primary properties and so makes them objective and observer independent, it is not an objective, observer independent matter which primary properties (if any) are which colors (p. 208)

Jackson (1996) argues that the prime intuition for his position is:

> that the colours are presented in colour experience and so are causes or potential causes of things looking one or another colour, that colours are not dispositions to look coloured. They are instead the categorical bases of dispositions to look coloured. Moreover, the categorical bases of dispositions are, we know, one or another complex of primary properties of objects, perhaps in conjunction with their surroundings (p. 204).

Jackson (1996) draws an analogy for his position with the concept of heat. He points out that feelings of heat are the putative presentations in perceptual experience of heat. But heat is not the disposition to cause inter alia sensations of heat but rather what causes the sensations of heat and the various phenomena associated with heat. But the complex primary quality that does the causing in the right way is molecular kinetic energy and, thus, heat is molecular kinetic energy.

Jackson and Pargetter (1987) have what I take to be a strong argument against stating that colour is a disposition. They point out that:

> The trouble for identifying colours with dispositions to look coloured is that it is inconsistent with the prime intuition that colours are properties presented in the visual experience of having something look coloured. But it is not a prime intuition that fragility is a property presented in experience, and so we do not need to give itself a causal role with respect to experience. We perceive colour, but infer fragility [my emphasis] " (p. 31).

If we look at typical examples of dispositions we don't see the disposition. Dispositions, like fragility, solubility, flexibility, elasticity etc., are all inferred. We don't see them as we do with most primary properties. As Jackson and Pargetter (1987) say; " If colours are physical properties of objects, then they are as objective and primary as shapes. " (p.31). We obviously see shapes we don't infer them. It is interesting that McGinn (1996) makes the same argument about inferring and colour without acknowledging Jackson and Pargetter. I will discuss McGinn in more detail in Chapter 16.0. It is also interesting that more recent work on colour and dispositions refers to the problem of colours not looking like dispositions without referring to Jackson and Pargetter (Byrne, 2000; Langsman, 2000). Harvey (2000), in a paper on 'Colour-dispositionalism and its recent critics', manages not only to fail to mention the issue but even fails to reference Jackson and Pargetter (1987), Jackson (1996), and McGinn (1996) as possible critics.

Jackson's argument that colour is a categorical property and not a dispositional one is disputed by other philosophers (Martin, 1994,1996a, 1996b; Martin and Heil, 1998, Molnar, 1999; Mellor, 1991; Heil, 2002).

Martin and Heil, (1998) argue that:

every property has both a qualitative (or 'categorical') and a dispositional side or aspect. These traits are correlative and inseparable.........The notion that real empirical properties might be purely non-dispositional or qualitative, the notion that they might be wholly 'categorical ', is as much an abstractive myth as is the idea of pure dispositionality (p. 289).

The concept of a disposition is one which has many interpretations (Crane, 1996). Bigelow and Pargetter (1999) point out that Martin has put forward a strong view about dispositions. Martin argued that truths need truthmakers. They say:

If attributions of dispositions to agents are to be true, he (Martin) taught us, then there must things in the world which make those attributions true. Thus, there must be ' something going on inside us,' to serve as a truthmaker for any attribution to us of the behavioral dispositions (Bigelow & Pargetter, 1999, p. 621).

However, Martin and Heil don't want to say that this something inside us is only a categorical property, as does Armstrong (1996c; Prior, Pargetter and Jackson, 1982; Jackson, 1996). They emphasize that it has both categorical and dispositional aspects. By contrast, Molnar (1999) wants to argue against any categorical properties by saying that it is dispositional properties all the way down. He says that:

When the analysis is applied to the powers of macroscopic objects, one finds that the causal base consists of other dispositional properties of their structures. When the analysis is applied to structureless entities, no causal bases can be found (p. 9). What does Molnar mean by structureless entities? He points out that things like electrons and quarks have no structure, because they are powers but there is no distinct property capable of realizing the relevant role. He says that:

In the Standard Model the fundamental physical magnitudes are represented as ones whose whole nature is exhausted by their dispositionality: that is, only their dispositionality enters into their definition. Properties of elementary particles are not given to us in experience: they have no accessible qualitative aspect or feature. ... there is thus a strong presumption in favour of saying that the properties of the subatomic particles are dispositions (p. 13).

Jackson (1996) accepts the possibility of "bare" dispositions in such cases, but says that not all cases are like the fundamental particles. He says that:

> When there are dispositional bases it is the bases and not the dispositions themselves that do the causing (p.202).

He would argue that colour is the dispositional base, but he would also concede that this base would be based on physical dispositions in the object, such as interactions with photons, which in turn have structured physical bases.

I find it difficult to conceive of colour as both a categorical property and a disposition to produce colour. Does that mean that colour is acting simultaneously in two ways? First, is it a colour process in a subject's brain which is produced by the visual system? Or is it something in objects which is detected by the visual system? It would appear to me that it cannot be both at the same time, as there would be two types of colour in the world. Heil (personal communication) and Martin (1996) evoke the concepts of 'reciprocal dispositions' to solve this problem. That is, dispositions of objects or radiation sources and dispositions of the visual system. There is said to be no one to one correspondence between colour experiences and one of the reciprocal partners (i.e. the external one). While it is clear that both the external objects and the visual system have a role to play, as Jackson emphasizes by stressing normal conditions, this does not account for two possible forms of colour.

The most detailed account of colour as a disposition by Martin and Heil has been expounded by Heil (2002) in an excellent forthcoming paper. Heil (2002) argues that dispositions are intrinsic properties of objects possessing them and every concrete property is dispositional. He also stresses that a manifestation of a disposition is a manifestation of reciprocal disposition partners. Heil then goes on to consider colour as a secondary quality. He argues that Locke described secondary qualities as powers to produce certain kinds of ideas in us. Heil does not agree with this interpretation. He asks are secondary qualities pure powers, so that the nature of a secondary quality is exhausted by the contribution it makes to the dispositionalities or powers of its possessors? He thinks that secondary qualities are not distinct from primary qualities as an object's possession of a given secondary quality is a matter of its possession of a certain complex primary quality. Heil puts forward a rather odd argument about primary qualities in support of his case. He says that primary qualities must be dispositional as well as qualitative (or in his terms categorical). He uses the primary quality of shape to demonstrate this. He says that spherical objects have dispositions to roll, to reflect light in a particular way, to indent sand in a particular way. I would dispute that these are dispositions. Just by looking at the shape one can see and conclude what the object will do in these circumstances. With a disposition, such as solubility or fragility, one cannot tell if it has the disposition just by looking at the object. It is necessary to test them for the possession of the disposition. So I would argue that many qualities of primary things, that we can observe, are not dispositions. They would, of course, have dispositional properties as well in some circumstances, but they would not be related to sphericity per se (e.g. a metal spherical object would melt if heated).

Heil argues that the possession of this complex primary quality, the object would look a certain way to an observer, but this anthropocentric way of picking out the disposition would not turn those dispositions into something subjective. He says that: " The dispositions are there, mind independently, in the objects " (p. 6). In this case, where is the reciprocal manifestation in this situation?

Heil goes on to emphasize the anthropocentric nature of colour. He says that if you ask why an object looks spherical, then the answer is simply because it is spherical. If you ask why an object looks red, then the answer is a complex dispositional story. He says that:

> the surface of the object has a particular character; the surface structures light radiation in a particular way; light radiation so structured, in combination with our visual system, yields an experience of red. The features of the object responsible for structuring the light radiation are perfectly respectable properties. A taxonomy in which these qualities feature would be of little interest to physics, however. In sum, secondary

> qualities are not properties objects possess alongside, or in addition to, their primary qualities. That is why, in giving an inventory of fundamental properties, physics need do no more than list the primary qualities. These, suitably, combined, make up the secondary qualities. (pp. 6-7).

I agree that this analysis is in keeping with a dispositional view of colour. However, I still think there is a problem of where colour is located with the reciprocal dispositions. Heil feels there is no problem as he says that;

> . if all this is taken into account, it seems the truth makers for color predicates will vary widely. " Is red "could be satisfied by properties of surface objects, by structured light radiation, and perhaps by internal goings-on (as when you describe an after-image as red). Does this imply a rejection of color realism? We doubt it (p. 9).

To me this seems to imply that there could be three locations of colour ands most likely a subjective location, given the visual phenomena I am proposing to discuss.

Heil (2002) follows Akins and Hahn (2000) in distinguishing three things about colours:

(1) colours objects have

(2) colour appearances: experienced colors of objects

(3) colours objects are judged (or believed) to have. (p. 10)

The work of Akins and Hahn will be discussed in detail in Chapter 10.0. Heil points out that these three aspects can vary independently in that the colour an object actually has does not vary, as experienced colours do, with changes in lighting or with changes in the observer's visual system. In looking at this variation, Heil does not mention the colour phenomena I am concerned with directly, but it is implied. These phenomena suggest that colour is not in the world, but is subjective. Heil says that:

> We can treat colors dispositionally to a first approximation, colors are dispositions to produce experiences of certain sorts in observers (p. 12).

I think a better account can be given on the basis of Jackson's theory that colours are the causal categorical properties of objects because dispositions are not causes (Prior et al., 1982). This will provide an answer to what Heil calls the really challenging problem for a psychological account of colour, which " is the explication of the relation of color experiences to color judgments " (p. 13).

Heil (2002) rejects what he calls the idea implicit in much philosophical writing on colour that either colour predicates designate properties of objects or they designate subjective, mind dependent properties. Heil says that:

> there is no such simple story available for color, Color experiences are mutual manifestations of properties of structured light radiation and properties of the visual systems of conscious creatures. Color judgments are in some fashion grounded in these experiences. Very different properties of objects can result in the very same color judgments, and similar properties can yield different colour judgments. This does not show that colors are subjective or mind dependent. On the contrary, the story we are telling is objective at every point. What it does show is that in order to understand the basis of color classifications, we need to know a lot about the propensities of objects to structure light radiation in particular ways and the visual systems of perceivers. None of this would come as a surprise to color scientists (p. 13).

One can simply say that most colour scientists think that colour is a subjective property and they base this on the colour phenomena I have and will be discussing. Also many philosophers take this view as Campbell (1993) has pointed out. Thus, this still leaves open the problem of where Heil's mutual manifestation is localized. To answer this issue, in this thesis, I will endeavour to develop a new theory of these categorical properties that supports a primary quality view and that rules out a dispositional account in terms of any mutual manifestation. Heil, in some personal comment, has said to me that if colour is a disposition of objects, then colour is in the object and the manifestation is in us. However, I still think that this leaves the problem of two locations for colour. However, I think Heil and Martin have raised some substantive issues that I hope to address.

Not all theorists are averse to multiple locations of colours. For example, Langsam (2000) seems to have no difficulty in proposing two forms of colour. He says that:

> I have argued that experience must distinguish between objective properties such as colours and subjective properties such as colour appearances if it is to succeed in presenting colours as properties of physical objects. (p. 74).

However, Jackson concedes that there is a problem in specifying exactly what the complex of primary properties consists of for colour. This difficulty is based on the problem colour phenomena such as metamers etc, as I stress. Thus he says:

> the primary quality account of color should regard color as relativized to a kind of creature and a circumstance of viewing. The primary quality account is the result of combining a causal theory of color—the view that the colors are the properties that stand......in the right causal connection to our color experiences... with empirical information about what causes color experiences; and a causal theory of color takes as fundamental color for a kind of creature in a circumstance.....I will be concerned principally with color in a thoroughly anthropocentric sense tied to normal humans in normal circumstances (p. 204-206).

Jackson (1996) proposes that unifying distal property of colour are the triples of integrated reflectance proposed by Land (1977). It is ironical that Jackson chose this mechanism to underlie a primary quality approach, as Hilbert (1987) points out that Land is a species of subjectivist. Land (1983) has argued that colours are the creation of brain mechanisms that compute colour descriptions based on retinal stimuli and that "what we know as reality is the experience at the terminal end of this computation" (p. 5164).

Jackson contends that this triples approach gives a not excessively disjunctive account of colour. Jackson does not go into any other scientific detail, but instead presents logical arguments against the dispositional and revelation approaches to colour (Johnston, 1992) and the unity account of colour (Campbell, 1969), in support of his disjunctive theory. Campbell (1993) argues that this neo-Lockean approach will only work if every feature of colour can be matched with a feature of the physical property. But Campbell (1993) asserts that " colours have properties not to be found in their physical causes" (p. 259). Campbell bases this assertion on the existence of the opponent-processing theory of colour vision and the existence of unique hues and complementary colours, which are not features in the proposed physical properties.

2.3 Wavelength Realism

Campbell has described wavelength realism as "Newton's legacy", being a hangover from Newton's work in discovering the spectrum by passing sunlight through a prism. The main modern proponent of wavelength realism is Armstrong (1968, 1980,1987,1993). Armstrong (1980) says that:

> the real colour of a surface is determined by the nature of the light-waves emitted from that surface. If a surface looks red, and is emitting light-waves of a sort or sorts characteristic of red surfaces, it is red. If it looks red, but is not emitting such a sort or sorts of light-waves, it only looks red. (p. 109).

Later, Armstrong (1993) modified his views and said:

> What I did and do accept about colour, though, is what Campbell calls 'disjunctive realism'. Physical redness is not merely an idiosyncratic property of no particular physical (as opposed to biological) significance. It is, or may well be, an irreducibly disjunctive property (because of metamers as Campbell explains). (p. 271).

Campbell (1993) also criticized wavelength realism, which asserts that colour is not a categorical property of surfaces, but rather of the light by which we see the surfaces. This realism is also open to the opponent process criticisms, but Campbell concentrates on criticisms based on Land's (1977, 1983) work with Mondrian displays and the existence of metamers. The Mondrian work shows that different colours can be seen on patches that reflect identical wavelengths. Metamers appear the same colour even though they reflect different wavelengths. Both these observations are difficult for wavelength realism. In fact, Campbell says that metamers provide "the definitive refutation of wavelength realism " (p. 254). Thompson (1995) also criticizes wavelength realism by arguing that colour constancy refutes it, because colour does not change with a change in the illuminant. However, MacAdam (1985) points out that it depends on the type of illumination:

> if a surface is illuminated by light of substantially a single wavelength, it will reflect only light of that wavelength... green paint may nevertheless be made to take on any hue of the spectrum if it is suitably illuminated. (p. 5).

Thus wavelength realism in the context of colour constancy depends on how broad is the spectrum of illumination, and green paint will still look green if enough of its dominant wavelength is present in the illumination (Helson & Jeffers, 1940).

2.4 Reflectance Realism

Campbell (1993) also criticizes another form of realism: reflectance realism. However, he only considers Land's work and does not consider the work of Hilbert, who has proposed a strong version of reflectance realism. As I pointed out earlier, it is rather ironical that Land has been associated with realism, because as Hilbert (1987) himself has pointed out that " Land, whose work I cite in arguing for objectivism is himself a species of subjectivist " (p 17). It is doubly ironical that other objectivists about colour also cite Land's retinex theory of triples of integrated lightness reflectances as the physical basis behind colour (Jackson, 1996; Matthen, 1988). Land (1977), on the basis of his work, reasons that since the flux entering the eye is not related to the colour, then colour judgements must be made on some information which the flux carries. Land proposes that since there are three linked receptors in the retina, the critical variables are three reflectance lightness triples that are integrated across the retina. The psychophysical correlate of lightness is the surface reflectance of an area relative to the average reflectance of its surround. Thus metamers form families, all of whose members have reflectance triples in common.

Hilbert (1987) also proposes a reflectance theory (anthropocentric realism) based on Land's integrated triples. Hilbert (1987) argues that there are two main options for a possible physical correlate of colour. One is surface spectral reflectance, i.e. the disposition of a surface to reflect the percentage of the incident light at each wavelength. To measure the surface spectral reflectance of a given point on the surface of an object, the ratio of the flux of the incident light to the flux of the reflected light is measured for each wavelength. These ratios, says Hilbert, are stable properties of objects and are independent of the illumination, such as the intensity and wavelength of light reaching the eye, which is given by the spectral power distribution of the light. This is the product of the surface spectral reflectance with the power distribution of the incident light. Hilbert (1987) stresses that there are two main options for a physical correlate of colour. One is surface spectral reflectance cited above, the second is the complex property of having a surface spectral reflectance such that the spectral power distribution of the reflected light is characteristic of that colour. This second option is a wavelength account of colour; and wavelength will vary with illumination. It might seem prima facie odd to regard an objects colour varying with changes in illumination, but one example will be presented later, in the case of Alexandrite (Nassau, 1983). Hilbert argues for the first option on the basis of the problem of metamers, Land's Mondrian data and colour constancy, all of which he claims are not compatible with wavelength explanations.

Campbell (1993) advances two other arguments against reflectance realism. First, he stresses that reflectance realism is grievously incomplete, because it deals only with the case of opaque bodies whose surface reflects light. But Nassau (1983) has listed up to 15 different physical causes of colour, such as incandescence, scattering, gas excitation etc.(see Table 1.1 in Chapter 8). Some of these processes produce colours that match those produced by reflection, yet none involve reflectance triples. Second, he comments on the remarkable effects of colour contrast on the perception of blacks, browns and olive greens. Campbell says:

> These are all colours in perfectly good standing in their own right, but they are severely anomalous for any reflectance realism, for none has a distinctive reflectance triple (p. 256).

That is, brown has the same reflectance triple as yellow yet it looks a different colour. Brown is just a darkened yellow, and similarly with olive green and greenish yellow. For Campbell the variety of physical bases of colours and the facts of simultaneous contrast ensures that:

> The unity of the colours lies in the unity of the response they engender in creatures with a colour vision like ours. It does not reside in any extra-animate physical reality (p. 257).

On the basis of this type of argument many philosophers (Hardin,1988; Lund,1994; Tolliver,1994; Maund,1994) settle for a form of subjectivism about colour. Campbell (1993) points out that subjectivism in all its forms are basically projectivist about colour and " every projection theory is an error theory " (p. 265).

Campbell (1993) says that:

> error theories are fall-back positions. They do not recommend themselves as inherently plausible: they are positions to which one is forced, reluctantly, by the untenability of alternatives.... Indeed, error theory about colour is not just a fall-back option: it is a desperation option (p. 265).

Despite these strong criticisms of various forms of realism about colours, which appear to lead to subjectivism, this thesis will attempt to revive what I call photon energy / wavelength (PE/W) realism on the basis of some new approaches to these controversial colour phenomena. I prefer to describe my theory as PE/W, because Nassau (1983) has shown that photon energy, which is correlated with wavelength, plays a most important role with electrons in most microprocesses underlying colour. This point will be taken up later in the thesis in Chapter 8.0. In the next section I will look at the role of metamers. This will be followed by an analysis of Land's retinex theory and then opponent colour process theory.

CHAPTER 3.0

3.1 Metamers and the Evolution of Colour Vision.

Metamers are a considerable problem for wavelength realism as the same colours are based on different wavelengths. In reading a recent book on colour vision by Kaiser and Boynton (1996), I was struck by a brief statement:

> two such stimuli, which are physically different but visually indistinguishable, are called metamers. Stimuli that physically match, and for that reason look identical are called isomers. For stimuli that are physically different within the visible spectrum, metamerism is the exception rather than the rule; exact or even near metameric matches seldom occur outside the laboratory. This is fortunate, and it suggests that the amount of color discrimination that we possess is sufficient for all practical purposes (p. 125).

On reading further, I also found a statement by another visual expert:

> The existence of metamer sets is not widely appreciated outside of visual science. This is doubtless partly because metamers seldom occur under naturalistic circumstances, and partly because by definition, metamers appear identical. Thus, outside the laboratory, one would not ordinarily encounter a pair of metamers (Teller, 1991, p. 53).

I corresponded with both these authors on this issue about the evidence for these assertions. They kindly replied as follows: Boynton said:

> I don't recall that I had any specific evidence for the claim. It is more of a logical argument, based on the idea that there are millions of discriminable colors, so that the probability that any two natural samples would look exactly alike, though physically different, would seem vanishingly small (personal communication).

Teller writes:

I guess the intuition is based on the idea that most natural objects probably have broad spectra, and things that look a similar color are probably made of similar substances, so they are probably isomers rather than metamers (personal communication).

What are the implications for wavelength theory if it turns out that metamers do not occur in natural objects and what type of evidence can support such an idea?

One of the important aspects of the spectrum of natural objects is the claim that they have very broad spectral distribution. Maloney (1986) has stressed that several quantum interactions lead to natural objects having very broad spectra without the profiles of metamers. This evidence will be discussed further in Chapter 8.0. While in general this proposition of broad spectra appears to be true for most objects, it would seem more important to consider this topic in connection with the evolution of human colour vision.

It is not often realized that the reflectance spectra of all natural objects in an animal's environment fall into 3 main classes according to ecologists (Osorio & Bossomaier, 1992). The three classes all have broad spectra; thus animals are not exposed to narrow band stimuli. The three classes are:

(1) "grey-red" which consists of most inorganic and many organic surfaces, including tree bark, dead leaves and animal melanin pigmentation. All these reflectances " increase monotonically from short to long wavelengths, the slope and precise form of the function gives various grey, brown/yellow or reddish appearances " (see Figure 1.0) (Osorio & Bossomaier, 1992, p. 218).

(2) "leaf-green " which is the reflectance of the leaves of land plants and they consist of a broad spectrum which peaks at about 555 nm due to a chlorophyll reflectance peak. Lythgoe (1979, p. 131) who drew attention to this peak, also pointed out that leaves of varying ages or species differ mainly at the long wavelength end of the visible spectrum (Figure 1.0).

(3) "leaf contrast" which are spectra of fruit and flowers that have evolved to be conspicuous to pollinators and frugivores. These leaf-contrast surfaces usually

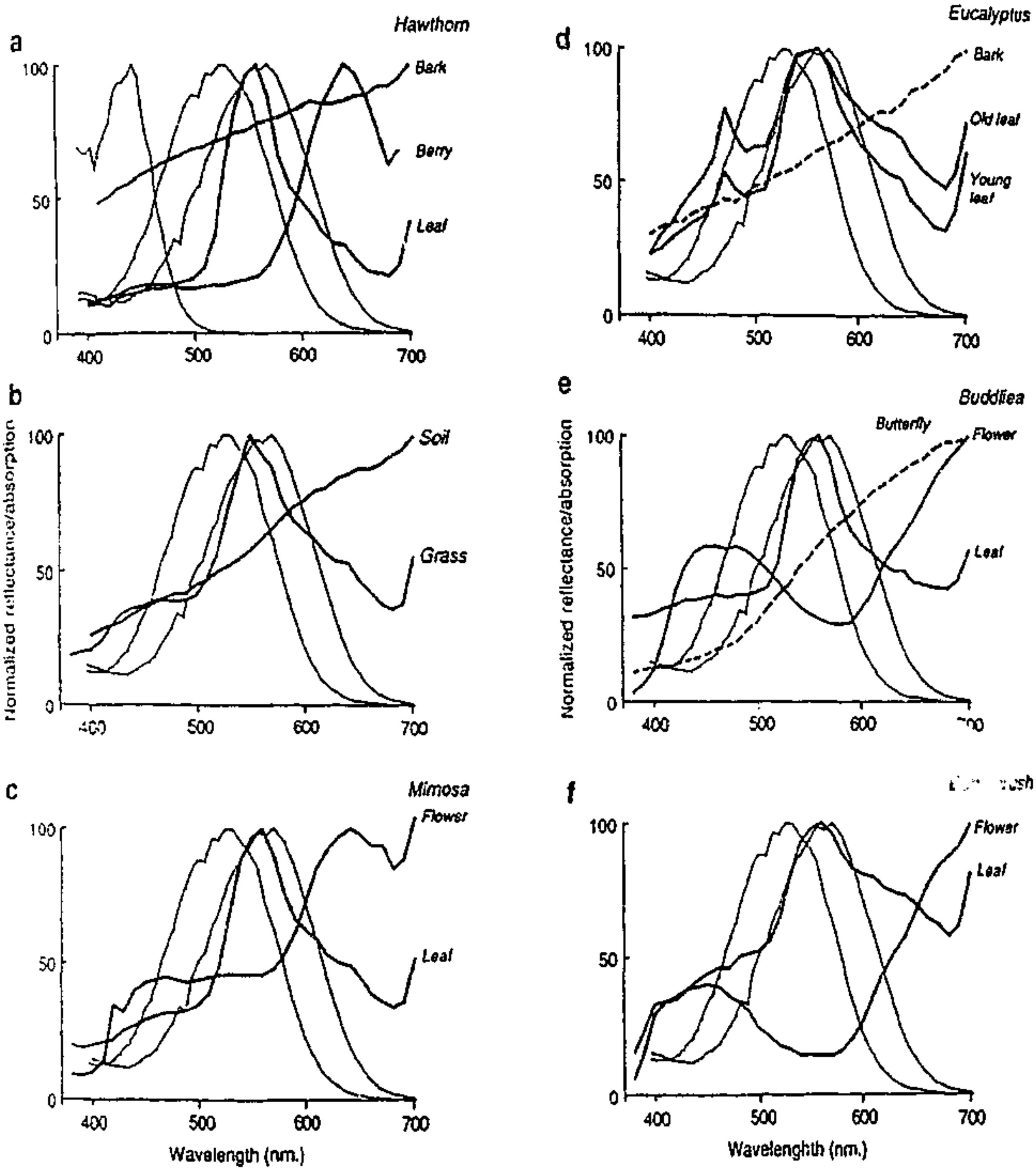
Fig. 1: reflectance spectra of examples of the three types of objects in the natural environment.

(a): spectra of the bark, leaf and berry of Hawthorn. Also displayed are the spectra of the three cones.

(b): spectra of soil and grass and L and M cones.

(c): spectra of leaf and bark of Mimosa and spectra of the L and M cones.

(d-f): spectra of flower and leaf for Eucalyptus, Budlea and Bottlebrush. Also spectra for L and M cones. (from Osorio and Bossomaier, 1992).


a
Hawthorn
Bark
Berry
Leaf
b
Soil
Grass
c
Mimosa
Flower
Leaf
d
Eucalyptus
Bark
Old leaf
Young leaf
e
Buddlea
Butterfly
Flower
Leaf
f
Flower
Leaf
Normalized reflectance/absorption
Wavelength (nm.)
Wavelenghth (nm.)
0
50
100
400
500
600
700

reflect a peak where leaves absorb, at wavelengths below 500 nm and /or above 600 nm (Figure 1). These stimuli present a colour contrast against a leafy background.

Mollon (1991) in discussing the evolution of primate colour vision points out that it has often been suggested that colour vision, in the case of surfaces with the same luminance but different colour, serves particularly to detect edges between equiluminant surfaces (Gouras & Eggers, 1983). However, Mollon notes that it is rare in nature for one surface to lie in front of another, in such a way that both have the same luminance or the same angle to the incident light or that the nearer surface throws no shadow on the farther one. Thus Mollon argues that the general problem for colour vision in the forest environment, in which our colour vision evolved, is to detect objects that lie in a situation:

> when the background is dappled and brindled, when, that is, luminosity is varying randomly... Such a variation in luminosity can arise because the illuminant is interrupted by foliage; or it can arise because the background consists of component surfaces that lie at varying angles to the illuminant or (in the case of new and old leaves) themselves vary in reflectance (Mollon, 1991, p. 308).

Mollon proposes the theory that our trichromatic colour vision evolved with primates in a forest environment, in which colour was one of the cues to identify fruits, plants and particular trees. In the case of fructivorous primates, trichromatic colour vision would have the major function of discovering the state of ripeness of fruit from the external appearance in this varying background of leaves. Mollon (1997) visited French Guiana where ecological research was being carried out in a primary, uninhabited tropical rain forest (Charles-Dominque, 1993). He studied the red howler monkey (Alouatta seniculus) which had recently been shown to be a trichromat, like the macaque (Jacobs et al., 1996). They measured the reflectance spectra of the fruit eaten by this animal (the main item in the diet being fruit) and the reflectance of the background foliage, the noise against which the fruit signals must be discriminated (Figure 2.0). They showed that the photopigments of this animal are well matched to the discrimination of the fruit signals. The important

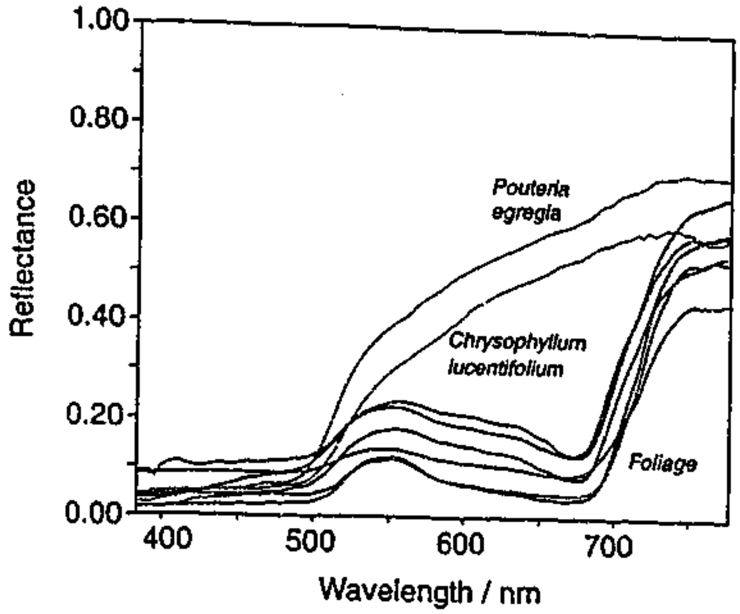


Figure 2: Reflectance spectra of the foliage and of the fruit eaten by the red howler monkey (from Mollon,1997).

point for our argument is that none of the signals looked like metamers in that they all had broad spectra without multiple peaks.

Mollon (1991) has argued for the evolution of 2 subsystems of colour vision in primates. The first subsystem to develop 500 million years ago was the addition of a few short-wave (violet sensitive) cones (around 435 nm) to a single class of cone with sensitivity in the range 510 to 570 nm. These short-wavelength cones, with their wavelength of peak sensitivity well removed from that of the middle-wave length cones provided mammals with a basic, dichromatic, system of colour vision (Mollon, 1991, p. 311). The differentiation of the second subsystem evolved about 30 million years ago, when the recent ancestors of the Old World primates had it overlaid upon the first. The second subsystem depends on the duplication of a gene that coded for the photopigment of the ancestral middle-wave cone. Nathan and his colleagues (1986) have shown that the inferred amino-acid sequences of the middle-and long-wave pigments are 96% identical and the 2 genes remain juxtaposed in a tandem array on the q-arm of the X-chromosome. The extreme homology and the juxtaposition of these genes render them vulnerable to misalignment when the X-chromosomes come together at meiosis.

Mollon (1991) has argued that there has been a co-evolution of fruit and primate trichromacy, in that all the species of the catarrhine monkeys and some New World monkeys have a middle-wave pigment close to 535 nm and a long-wave pigment close to 565 nm. What these monkeys have in common is that a substantial portion of their diet consists of fruit. Allman (1999) has shown that fruit eating primates have developed larger brains, particularly larger lateral geniculates, than leaf eating primates, thus indicating powerful evolutionary pressures on the brain and the visual system are based on this activity. Mollon (1997) wants to hypothesize from ecological work:

> that in both the Old World and the New there is a subset of trees that is disseminated only by monkeys... these trees constitute a significant component of the rain forest... It is instructive that the one task that particularly handicaps human dichromats is picking fruit— one needs colour vision not to detect luminous edges (which are rare in the natural

> world) but to discover targets against a background that is varying the randomly in luminance and form, as in the case of fruit among foliage. (p. 874).

Mollon (1995) sums up his theory as follows:

> The tree offers a colour signal that is visible to the monkey against the masking foliage of the forest. and in return the monkey either spits out the undamaged seed at a distance or defecates it together with fertilizer. In short, monkeys are to coloured fruit what bees are to flowers. With only a little exaggeration, one could say that our trichromatic colour vision—if not the entire primate lineage—is a device invented by fruiting trees to propagate themselves (p. 134).

Most recently, there has arisen a controversy about the cues for the evolution of primate colour vision. In contrast to Mollon, Lucas and his colleagues (Lucas et al., 1998; Dominy and Lucas, 2001) have argued that primate trichromatic vision evolved to detect young red leaves rather than fruit; i.e. a folivory explanation. In a set of recent papers Mollon and his colleagues (Regan et al., 2000: Sumner and Mollon, 2000 a, b) have examined this claim. They have concluded that leaves could play a role. They state that:

> Primate trichromacy could first have evolved to detect any fruit against leaves (rather than specifically those disseminated by primates), to detect edible yellow or red young leaves against mature leaves (Lucas et al.,1998). or to detect conspecifics. Colimbine monkeys are among the most folivorous of catarrhines, yet uniform trichromacy seems to be present in those species that have been examined (Regan et al., 2000, p. 273).

The main point is that whether the task is to detect fruits against foliage or young leaves again foliage, the optimal spectral tuning of the L / M cone pigments is the same. This extension allows the theory to encompass other trichromatic monkeys, such as the colobine, noted above, (Deegan and Jacobs, 1997), which feeds mainly on leaves.

I conclude from these data that trichromatic colour vision evolved under conditions in which there were few metamers and where a clear peak of one area of wavelength is present. Thus wavelength is correlated with colour without any of the ambiguities that can be induced in the colour system by modern methods of producing colours and dyes and pigments with spectra that have a number of discrete peaks, which can produce the same pattern across the cones. The development of coal-tar dyes and other artificial methods has allowed much wider range of colours than the colours produced by largely natural substances (Garfield, 2000).

What I am proposing here is that the emphasis on metamers in the current visual literature and the highlighting of them by philosophers is not relevant to the environment present in the development of human colour vision. I would argue that colour in these circumstances is the perception of largely single peaks of wavelength. This is a direct realist account of colour and thus it is also not necessary to have a disjunctive wavelength explanation of colour to account for metamers in the natural world. (Smart, 1975; Armstrong, 1987).

It could still be argued that the mere existence of metamers is sufficient to refute wavelength theory. Against this, I would argue that it is almost a form of trickery that one can fool the visual system with our modern methods of manipulating wavelength. As Kaiser and Boynton (1966) put it "even the cones can be fooled into allowing a metameric match between spectrally dissimilar lights " (p 142). Thompson (1995) in discussing reflectance realism says:

> At this explanatory level, colour vision is defined as that visual process that recovers information about invariant surface spectral reflectance...given this conception it is natural to explain approximate colour constancy as involving visual error. Surface colour metamers would therefore constitute a species of visual illusion (p. 103).

I believe that this argument applies to wavelength realism. We can produce coloured stimuli in the laboratory that have many peaks in their spectrum. Thus Judd and Wyszecki (1963) say that:

> if two curves (i.e., the spectral reflectance curves for two objects) differ in a complicated way , such as with three or more crossing points [my emphasis]....such specimens give rise to metameric stimuli (p. 103).

I would like to assert that such complicated crossings don't occur readily in nature. If they were, they would lead to many different combinations of wavelength producing equal excitations in the three cones. The important point is that the human colour system evolved without such metamers in the context of discriminating the peaks of wavelength of fruit from the peaks of wavelength of foliage and the peaks of young leaves from the peaks of older ones. Thus wavelength is the basis of colour for all practical purposes. Lennie and D'Zmura (1988) have put forward a different argument supporting the lack of metamers in natural surfaces. They say:

> The issue is whether there exists different natural surfaces that are metameric. Because a surface reflectance function can be represented as a sum of three components in the wavelength domain, its representation in the chromatic frequency domain is the sum of the Fourier transforms of the three components. Thus the chromatic frequency spectra of the basis functions tell us about the frequency content of the original surface. Maloney finds that the component functions contain little power at frequencies above 5 c /μm (i.e. reflectance changes slowly as a function of wavelength. Thus, to the extent that surfaces can be represented accurately by appropriate amounts of three basis functions that contain little energy at frequencies higher than 5 c /μm, different surfaces will not be metameric (p. 345).

I would like to emphasize strongly that most natural materials have a broad spectra of reflectance (Maloney, 1986). I will go into the quantum mechanisms underlying these broad spectra in Chapter 8.1. Maloney (1986) has pointed out that the half-width of a typical absorption band in nature is approximately one half of the visible spectrum, thus leading to broad reflectance spectra without the multiple crossings of metamers.

It is interesting that Hilbert (1987), who is against any wavelength explanation of colour, concludes that:

> The small number or parameters required to account for existing variations in reflectance implies that metamerism may not be common. The visual system is not faced with the problem of determining a property that can vary in an unconstrained manner. Although there are possible differences in color that are undetectable in normal circumstances, the actual occurrence of such differences appears to be relatively rare. In general, objects that look to have the same color will have the same color (p. 130-131).

This is very encouraging support from quite a different direction for our claim that metamers don't appear frequently in the evolution of primate colour in the real world.

I am not asserting here that metamers do not play an important role in modern colour science. Teller (1991), despite arguing that metamers don't exist in nature, wants:

> to argue that one is interested in the causes of color appearances, but not in metamerism, is analogous to arguing that one is interested in the causes of similarities in facial structures, but not in identical twins (p. 59).

Teller points out that metameric stimuli are the basis of colour coding schemes or colorimetry, such as the CIE (Commission Internationale de L'Eclairage) system of colour space. But I would argue that the CIE measurement system supports a realistic view of colour as it allows instrumental measures of colour and Campbell (1972) has stressed that instrumental measurement distinguishes primary from secondary qualities. It is realized that CIE measures depend on the calibration with an "standard observer" and imaginary primaries, but they allow matching colours to be produced by instrumentation in different laboratories without the direct presence of observers in the measuring process. This suggests to me that it is an objective process for measuring external colour.

While I think this argument can be asserted to show that colour is a primary quality, my main conclusion for this chapter is that metamers are not present very often in nature. Thus our visual system developed to detect broad spectra and thus metamers do not necessarily provide " the definitive refutation of wavelength realism " as Campbell (1993, p. 254) claims.

This qualitative account was given a quantitative formulation by the hue-cancellation technique of Hurvich & Jameson (1957), in which green and red will cancel to yellow, and blue and yellow cancels to white. Hardin (1988) lays great emphasis on the opponent process cells found in the lateral geniculate nucleus (LGN) of the macaque monkey (De Valois et al., 1966), which appeared to give a neurophysiological basis for opponent colour processes. They found cells were excited by one part of the spectrum and inhibited by other wavelengths. They classified the units into 4 classes and gave them the initials of colour names and with + meaning excitation and - meaning inhibition (+R-G, +G-R, +B-Yand+Y-B). In fact, it became a text book account of colour that the receptors are trichromatic and post-receptor processes are opponent and would thus support Hering's model of the colour system.

However, more recently the concept of opponent processes in the Hering model has been challenged and questioned (Mollon, 1987, 1989, 1997; Mollon & Cavonius, 1987; Krauskopf, 1997; Teller, 1991; Webster & Mollon, 1991,1993,1994; van Brackel, 1993; van Brackel & Saunders, 1997; Jameson & D'Andrade, 1997). Van Brackel (1993) has produced a number of criticisms of Hardin and opponent processes, but, in general, while we will examine some points raised by van Brackel, we will also consider some more recent evidence.

Teller (1991) argues that the physiological evidence in primates does not correspond in essential detail to the scheme required by classical opponent process theory. She points out that the classical opponent theory does not just require the existence of two classes of chromatically opponent neurones:

> it requires two specific classes of opponent neurons, with the crossover (neutral) point- the wavelength at which the neuron's responses shift from positive to negative, or vice versa- of each type of neuron corresponding to the unitary hues signalled by the other type of neuron. A neuron cannot be said to code the "yellow/blue "dimension unless its crossover points occur at unique red and unique green, and vice versa.....The retinal coding scheme requires further recoding if neurons worthy of the names red/green and (particularly) yellow/blue are to emerge.

CHAPTER 4.0

4.1 Opponent Process Theory.

Hardin (1988,1992) has argued vehemently against any objective account of colour. He bases his argument on the nature of opponent process theory: He says that:

> Colors are not wavelengths, spectral reflectances, or any other physical characteristics of the world that cause human beings to have color perceptions.The central reason is this: For human beings and a variety of other animals, there are exactly four perceptually basic unitary hues, of which all other hues are composed in a pairwise fashion, but there is no such thing as a privileged set of exactly four basic wavelengths or spectral reflectances of which the other wavelengths or spectral reflectances are composed. The perceptual structure of colors thus has no counterpart in the domain of wavelengths of light, even though we normally see those colors because we are stimulated by light that has an appropriate wavelength configuration " (Hardin, 1992, p. 371).

Hardin (1988) argues there is no such thing as colour out in the world. Instead he proposes a neural subjectivism:

> we are to be eliminativists with respect to color as a property of objects but reductivists with respect to color experiences. The value of a program to reduce chromatic experiences to neural processes can be determined only by its success (p. 112).

As I said Hardin bases his arguments on the opponent process theory of colour, which started with Hering (1920/1964), who said that many of the fundamental observations about colour were unexplained by the trichromatic theory of Helmholtz (1924). Hering emphasized that red and green do not mix to produce a reddish green, and blue and yellow don't produce a bluish yellow. He proposed three channels: a white-black, a red-green and a blue-yellow channel.

Such neurons have not yet been seen in primate visual systems, and no one knows where or whether they will ever be seen (Teller, 1991, p. 52-53).

Hardin (1988) ignores the fact that even in the initial data of De Valois et al. (1966), the crossover points of the LGN cells did not match the crossover points expected by the classical theory. In fact, the cross-over points for individual cells range from 480 to 630 nm (Boynton, 1979, p 234-237). Jameson & A'Andrade (1997) point out that in this study the sensitivity of the cells does not agree with opponent theory in that the peak for yellow-plus LGN cells occur at 600 nm which is typically seen as reddish orange, not yellow. Also the peak for blue-plus cells is around 455 nm which is a violet. For green-plus cells the peak is 540 nm which is a yellowish green. In addition, cells in primate LGN do not adapt (Derrington, et al., 1984), so they could not mediate the adaptation effects thought to be involved with the so-called opponent cardinal directions in colour space. (Krauskopf et al., 1982).

Similar problems are present in cells of primary visual cortex (V1) in that they also have a broad range of R-G neutral points with a range similar to LGN cells (Zrenner et al., 1990). However, V1 cells do adapt, but not all cells show opponent processes like those required by Hering's theory. In some recent studies of V1, V2 and V4, (Yoshioka et al. 1996, Yoshioka and Dow 1996) tested cells with the 11 basic colour terms identified by Berlin and Kay (1969) to be found in 20 languages. These consisted of 8 chromatic colours (red, green, yellow, blue, orange, purple, brown, and pink); and 3 achromatic colours (white, gray and black). They found that there was about the same proportion of cells associated with the other 4 colours as with Hering's primaries (red, green, yellow and blue). They also found that red was associated with blue more often than with green. They called these cells end-spectrum cells.

On the basis of this and other evidence, Boynton (1997) has proposed that there might be multiple directions (perhaps eleven proposed above) in colour space rather than the two classical opponent ones. He says that:

> I would suggest that it would be more useful to consider our color space than to refer to opponent-color diagrams, and that one should accept

our conclusion that there are no differences between primary and derived basic colors except for the compound sensory aspect of the latter, which really does not seem to matter. I would argue that all eleven basic colors are perceptual fundamentals, and that the fundamental neural responses, as defined by Kay, Berlin, and Merrifield (1991), should be expanded to include all eleven. Their appeal to the early research of De Valois and his colleagues is misguided, if only because sensations surely do not arise from the lateral geniculate nucleus, which was the site of their recordings. Moreover, De Valois's use of the names 'red', 'yellow', 'green', and 'blue' to classify groups of data was entirely arbitrary and ignored a virtual continuum of opponent responses that exists as a function of crossover wavelengths in the data of individual units (Boynton, 1997, p. 148).

De Valois and De Valois (1993) have now acknowledged these possible errors and have proposed a new mechanism to save opponent process theory. They propose a third mechanism after the trichromatic first stage and the second stage opponent process. However, this theory is rather ad hoc. Hardin (1991) has attempted to reply to Teller about the broad crossover points by referring to some work of Young (1986), who reanalysed the data of De Valois et al. (1996) using a principal-component statistical analysis. This analysis suggests that the data might show a rotation of color space to be compatible with opponent theory, but it does not explain the broad crossover range

In the study by Krauskopf et al. (1982), considerable support was provided for colour opponent theory. They adapted with one cardinal direction (red/green) and found it did not influence colours in the other cardinal direction (blue/yellow). Krauskopf et al. (1982) did note that some of their results suggested selective effects when adaptation stimuli were modulated at non-cardinal directions.

Later, the original data was reanalysed using Fourier techniques (Krauskopf et al., 1986). They concluded that selective desensitization results from viewing stimuli modified in any direction, not just in the cardinal directions. It is interesting to note that Krauskopf who initially supported cardinal directions and opponent processes has now written a paper entitled "The paucity of evidence for cardinal mechanisms" (Krauskopf, 1997). In this and other papers, (Krauskopf et al., 1996; Krauskopf, 1997), he presents considerable experimental evidence, in addition to that cited above, that there are more directions in colour space than the cardinal directions of classical opponent theory. In the original Krauskopf et al. (1982) paper, the adaptation effects were all assessed with threshold measures.

However, similar experiments with suprathreshold measures (Webster & Mollon, 1991,1993,1994) have also shown adaptation effects at directions other than the cardinal directions, thus suggesting that the visual system does not correspond to the processes postulated by Hering. In another study by Mollon and Cavonius (1987), it was shown that adaptation with unique blue, which should leave the red-green proces s in equilibrium, produces a large impairment of wavelength discriminations at long wavelengths where only the red-green process should be in play: So much then for the independence of the cardinal mechanisms and the related unique hues. Mollon (1997) concludes that:

> thirty years ago we thought we understood the existence of four unique hues, hues that are phenomenally unmixed. Today this is perhaps the major unsolved problem of colour vision (p. 872).

Valberg (2001) in a recent review concludes that:

> unique hues are still without a unitary neural representation, and their physiological origin remains enigmatic (p. 1655).

The stress that Hardin puts on the identity of unique hues with opponent hues has been queried in some very recent literature. Webster et al., (2000a,b) has shown that the locus of unique hues in cone-excitation space does not line up with the four poles that are said to represent the four opponent processes (e.g. Red, green, yellow, and blue). This can be clearly seen in Figure 3A. In the six subjects only unique red lines up with opponent red. The other three unique colours are often at 45° from the opponent axis, which would appear to lie in the area for binary hues. Valberg (2001) also argues against identifying unique hues with opponent hues. He says

FIGURE 3A

Locus of unique hues for six observers within the SvsLM and LvsM plane. Curves plot the loci of unique red, green, blue, or yellow settings for stimuli that range in contrast from 10 to 60. Each panel plots the settings for an individual observer. Only the settings for red line up with the appropriate opponent processes axis.(from Webster et al., 2000b).

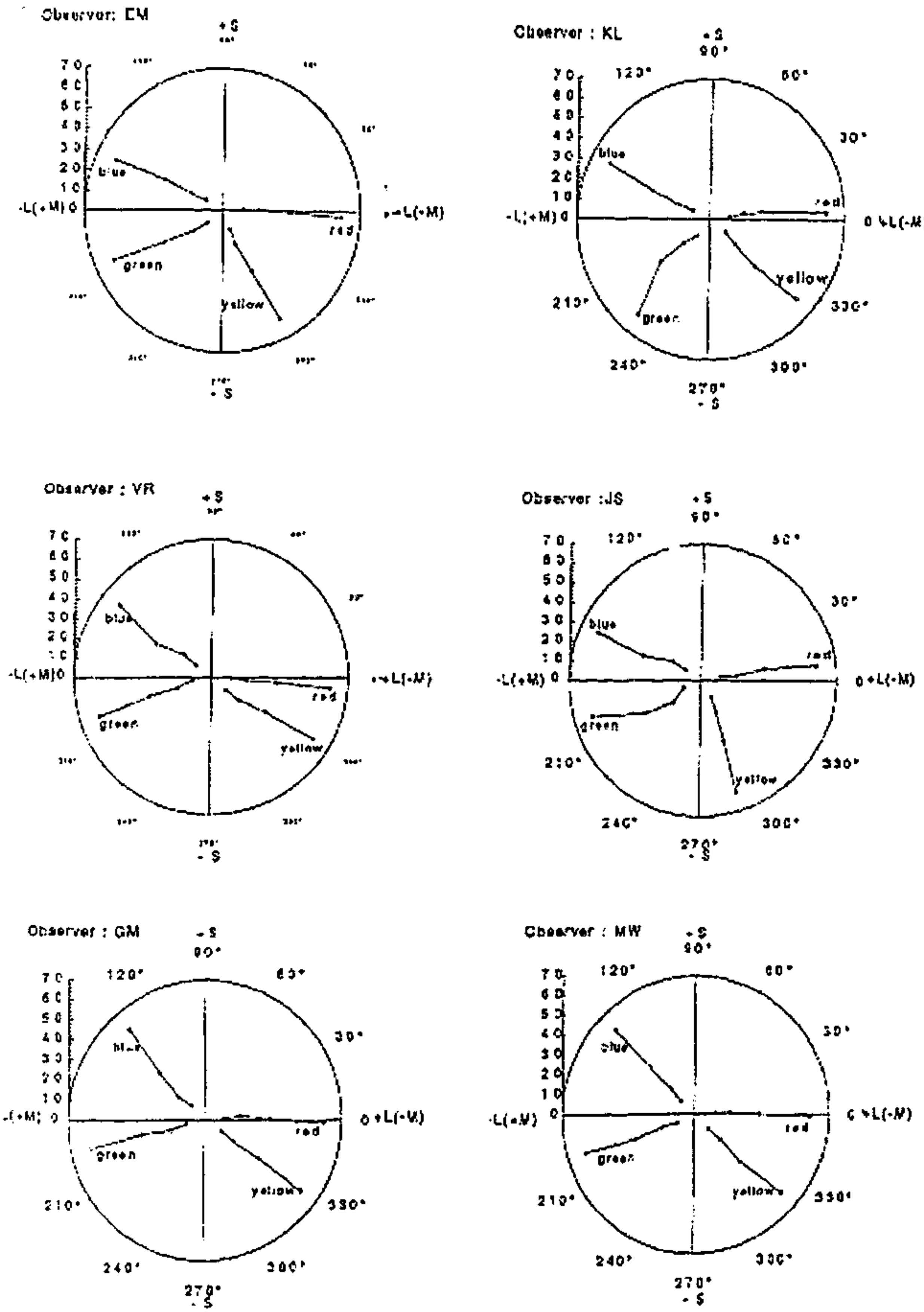
little hesitation was shown in relating unique and opponent colour pairs directly to cone opponency. Despite evidence to the contrary (Valberg, 1971; Burns, Elsner, Porkorny, & Smith, 1984), textbooks have, up to this day repeated the misconception of relating unique hue perception directly to peripheral cone opponent processes (p. 1649).

Mollon and Jordan (1997) go on to summarise the situation perfectly when they say that:

When chromatically antagonistic signals were first recorded in the retinae of fish (Svaetichin and MacNichol, 1958) and in the lateral geniculate nucleus of macaques (DeValois et al., 1966), it was widely assumed that Hering had been vindicated and that neural channels of the primate LGN corresponded to the red-green and yellow-blue processes of Opponent Colours Theory. The standard zone model of the 1960s had a receptoral "Helmholtz"stage and a second "Hering" stage (Walvren, 1962). Such a view still survives in psychology textbooks and other secondary sources. Today, however, most colour scientists are agreed that the chromatically opponent cells of the early visual system (the "second stage" of models of colour vision) do not correspond colorimetrically to red-green and blue-yellow processes.... recognizing this discrepancy, the authors of recent models of colour vision have usually postulated a "third stage", in which the second stage signals are transformed to give channels that do correspond to those of Hering (DeValois and DeValois, 1993; Guth, 1991). It may be that a third stage does exist, but electrophysiological recording has not yet revealed it (p. 382).

Webster (1996) in a review paper also sums up in favour of multiple channels:

Many phenomena in colour vision, from colour naming to threshold contours for different colour-luminance directions, can be parsimoniously accounted for by assuming only three post-receptoral channels. Yet most such results could also be explained by assuming multiple colour-luminance mechanisms, each tuned to a different colour-luminance axis. There are now



Observer: EM
+S
-L(+M) 0
+L(-M)
blue
red
green
yellow
-S
Observer : KL
+S
90°
120°
60°
30°
0 +L(-M)
-L(+M) 0
blue
red
yellow
green
210°
330°
240°
300°
270°
-S
Observer : VR
+S
blue
red
green
yellow
-L(+M) 0
+L(-M)
-S
Observer : JS
+S
90°
120°
60°
30°
blue
red
green
yellow
-L(+M) 0
0 +L(-M)
210°
330°
240°
300°
270°
-S
Observer : GM
+S
90°
120°
60°
30°
blue
red
green
yellow
210°
330°
240°
300°
270°
-S
Observer : MW
+S
90°
120°
60°
30°
blue
red
green
yellow
-L(+M) 0
0 +L(-M)
210°
330°
240°
300°
270°
-S
70
60
50
40
30
20
10

results from a variety of different paradigms showing that sensitivity can be selective for more than three fixed directions within colour-luminance space, suggesting either that there are multiple mechanisms or that mechanisms can change their tuning properties depending on the specific experimental conditions......multiple channels are also inconsistent with the specific notion that unique hues reflect the nulling stimuli for individual channels and thus add further to questions about the true substrate of colour sensations. (p. 596-597).

Barlow and Foldiak (1989) have suggested that it might not be multiple channels but only a small number of chromatic channels and these are not only desensitized by adaptation, but are caused to rotate from their natural alignment to the cardinal directions. This suggestion is not supported by the following experiment.

D'Zmura (1991), in an imaginative experiment, used a "popout" detection design developed by Treisman (1996) and her colleagues. He was able to show that there are multiple, hard-wired channels acting in parallel rather than just the two proposed by standard opponent theory. A moderately-saturated orange stimulus "popped out " (detected with less than 500 msec latency) in the presence of either red and green or blue and yellow distractors and the "popout " occurred with no increase in latency, even when the number of distractors was increased to 30. Similar results were found for unique red and unique yellow targets with opponent process distractors. Such distractors evidently provide negligible noise power to the mechanisms that are mediating the detection of the colour target. Another important point of this experiment is that it does not depend on a difference between threshold and super-threshold measures, which is controversial in the experiments cited above. The short latency of the "popout" mechanism suggests that adaptation would not be a big factor in the way suggested by Barlow and Foldiak (1989).

D'Zamura (1991) claims that these detection mechanisms, as a group, form a hard-wired fine-grained representation of hue within the central visual field, rather than depending entirely on the two opponent mechanisms. D'Zmura (1991) does not want to replace the standard colour-opponent mechanisms entirely, as they do explain much data on colour appearance. This is a view that I strongly agree with. However, his results do suggest that the assumption that there are only these two mechanisms in the brain is implausible. In a more recent paper, D'Zmura and Knoblauch (1998) showed multiple directions in colour space using a noise masking technique. In a recent study, Goda and Fujii (2001) reported that:

> the discrimination of the color distribution is mediated by multiple chromatic channels that are tuned to a variety of directions in the color space (p. 2475).

Thus Hardin's claim that there is no correlation between physical properties and colour detection mechanisms in the brain is not supported. D'Zmura (1991) stresses that physiological results also support such a multiple detection organization for higher-level chromatic mechanisms. For example, Lennie et al., (1990) have shown that the peak hue sensitivities of single neurones in macaque V1 are scattered more uniformly than the clustering about the opponent axes seen in macaque lateral geniculate nucleus. A similar pattern of sensitivities are seen in macaque V4 (Schein and Desimone, 1990).

Another general problem for colour vision is how to separate colour and luminance information contained in opponent cells (Kingdom and Mullen, 1995). This problem has not been addressed by advocates of opponent processes such as Hardin (1988). Kingdom and Mullen (1995) have summarised the evidence about this problem. They point out that 80% of the ganglion cells in the primate retina show single cell opponency, that is, they are excited by light of one wave length and inhibited by light of another. These cells described as P cells (or parvocellular cells due to their projection to parvocellular cells in LGN) theoretically have the property that in principle allows them to provide unambiguous information about wavelength. However, they are also very sensitive to luminance contrast. Given their large number and their small receptive field size, they are most likely to be the principal source of information about fine spatial detail (Kingdom & Mullen, 1995). Thus they perform a "double duty" by carrying information about both colour and luminance contrast, which is described in the literature as "multiplexing" (Ingling and Martinez-Uriegas, 1983).

This multiplexing property is an inevitable consequence of the fact that they have both cone opponency and spatial opponency. Similar considerations apply to P-cells in the LGN. Kingdom and Mullen review the evidence of how it is possible to decode or demultiplex the signals to provide unambiguous information about luminance, or colour, or both. They conclude that there is no clear cut model to achieve this among the many reviewed (including the model of DeValois & DeValois (1993) discussed above). Nor is there evidence of cells doing this unambiguously in the early part of the visual system, i.e. the retina, LGN and V1. They point out that the psychophysical literature clearly indicates that this ambiguity between colour and luminance is overcome and they vaguely suggest that it occurs beyond the early cortical level, without indicating where. It should be stressed that this is a major problem for any Hering type opponent theory which has spatial detail handled by the black and white channel, independently of the red-green and the blue-yellow channels. Of course, the ambiguity presents a problem for all colour vision theories, but it would appear to give opponent theory the most trouble with its emphasis on spatially opponent receptive fields.

The issue here is not that there does not exist a variety of opponent types of cells, it is just that there is no convincing evidence for exactly two well determined pairs of opponent hues (van Brackel & Saunders, 1997) that can clearly separate colour from luminance. Thus, Hardin's repudiation of the objectivity of colour on the basis of opponent processes and unique hues does not appear as convincing as when he first proposed it. Perhaps the reason for opponency has been misunderstood. It might be more like Livingstone and Hubel's (1984) suggestion:

> We assume that the point of opponency is to render ineffective things like diffuse light or white light, rather than permit a cell to have two kinds of response (p. 321).

It should be noted, however, that a recent functional magnetic resonance imaging (fMRI) study of human visual cortex (V1 & V2) gives some support for opponent processes in that it has shown the strongest responses to red-green and blue-yellow stimuli. (Engel et al., 1997). Although it is reported that many colours were tested, no data are presented on other colours other than red, green, blue and yellow. Given the work of Yoshioka et al. (1996a,b), it would be interesting to see exactly the type of response to the other colours in the proposed 11 basic directions of colour space that I am suggesting might be important.

Overall, I believe that the recent analyses of opponent processes suggest that it is not as damming for wavelength theory as has been proposed by Hardin (1988).

Finally, Hurlbert (1997) sums up our arguments about opponent processing as follows:

> Even more recent experiments requiring human observers to make colour matches after adapting to coloured lights demonstrate that the cardinal axes are not themselves unique, and that there may be many more than three cardinal types of neuron involved in recoding cone responses. Thus, both neurophysiological and psychophysical evidence point to multiple mechanisms encoding colour, each tuned to a distinct axis of direction, in colour ' space' and each independently susceptible to adaptation. Faith in the four unique hues, or in any fixed set of universal colour categories, must be in faith only, without firm empirical justification (p. 401).

Overall, this evidence suggests that there is a relationship between colour space in the world and colour mechanisms in the brain, There would appear to be mechanisms detecting many directions in colour space, that are related to external factors. There does not appear to be only opponent processes, which can't be related to external factors. In other words, there does not appear to be a structure in perceived colour that is not found in the physical causes of colour experience.

CHAPTER 5.0

5.1 Reflectance Realism and Retinex Theory.

It is interesting that the three major defenders of an objective approach to colour (Hilbert, 1987; Mothan, 1988; Jackson, 1997), all base their objective mechanism on the Retinex theory of Edwin Land. The word Retinex comes from a combining of the words retina and cortex.

Hilbert (1987), despite being an objectivist about colour, argues strongly against wavelength realism. He puts forward his own version of realism which he calls anthropocentric realism which is basically a form of reflectance realism (Campbell, 1993) but with a vital difference. Hilbert (1987) says that

> As the dispositionalist emphasizes, not every difference in reflectance corresponds to a difference in perceived colour in normal circumstances. The fundamental insight that is needed to provide such an account is that color perception and language give us an anthropocentrically defined kinds of colors, not colors themselves. It is this insight that makes it appropriate to describe the sort of realism I defend as anthropocentric realism. Perception does not reveal the whole truth about colors and the truth it does reveal is delimited by the characteristics of our perceptual systems....... The nature of our experiences only influences which of many possible kinds of color our color terms and perceptions refer to. The kinds themselves exist independently of our color experience and are fully objective. One way of describing anthropocentric realism is that the colors we perceive and talk about are objective although scientifically uninteresting kinds (p. 27).

The objective kind that Hilbert supports for color is surface spectral reflectance i.e. the disposition of a surface to reflect the percentage of the incident light at each wavelength. To measure the surface spectral reflectance of a given point on the surface of an object, the ratio of the flux of incident light to the flux of reflected light is measured for each wavelength. These ratios, says Hilbert, are stable properties of objects and are independent of the illumination. The intensity and wavelength of light reaching the eye is given by the spectral power distribution of the light, which is the product of the surface spectral reflectance with the spectral power distribution of the incident light. Hilbert (1987) argues that there are two main options for a possible physical correlate of colour. One is the surface spectral reflectance which he says will make colour a stable, illumination-independent property. The second is the complex property of having a surface spectral reflectance such that the spectral power distribution of the reflected light is characteristic of that colour. The second option is a wavelength account of colour and will vary with illumination. Hilbert argues for the first option on the basis of metamers, Land's work with Mondrians, and colour constancy, all of which he claims are not compatible with wavelength explanations. As we have potentially disposed of metamers as a fatal objection; we will now examine Land's work.

Land & McCann (1971) and McCann et al. (1976) carried out experiments with Mondrian displays and found that the colours did not change even though each colour patch reflected the same amounts of each narrow band of wavelengths. They concluded that:

> there is no predictable relationship between flux at various wavelengths and colour sensations associated with objects (Land & McCann, 1971, p. 1).

Other visual scientists don't agree with this conclusion. Boynton (1979, p. 333) in reply to the above assertion states that:

> on the contrary, when one measures the relationship under controlled conditions, data of astonishing reliability can be generated .

Boynton (1979, p. 333) then refers to his papers on colour naming to support this assertion. These papers show that there is a close relationship between colour and wavelength, but they don't answer the problem raised by different colours being based on the same wavelengths in Mondrians, or in other words, an extreme form of colour constancy.

However, the work of Land (1977) and McCann et al. (1976) has been thrown into doubt by the work of Young (1987). This work seems to have been unnoticed in the literature and only cited by Forsyth (1990) in an article on colour constancy. Young has shown that the output of the filters employed by Land and McCann, when taken in conjunction with the output of the tungsten light bulb in their projectors, leads to an artifact (Figure 3), in that they did not lead to the complete elimination of cues to the chromaticity of the Mondrian papers. In this figure, Young has demonstrated by digital processing::

> that " identical " reflected lights, although constrained to match radiometrically to the retinex criteria, are still different enough to be easily discriminable in chromaticity by a human (Young, 1987, p. 1732).

Young tested with 50 nm filters as used by Land (1983) and 10 nm filters as used by McCann et al. (1976). In both cases, the calculated CIE tristimulus values of the reflected light from the " strong" hues in his set of colour patches are clearly different and outside the MacAdam ellipse of an identical colour area (Figure 3). These CIE values would be clearly discriminable as different colours based on wavelength differences, even when the 10 nm filters are employed. Young concludes that the scope of the results " does extend to the " equated" paper results in all Retinex experiments conducted to date " (p. 1732) In other words, Mondrian experiments do not show that stimuli of equal wave length can be seen as different colours. Thus Mondrian displays do not carry the theoretical weight against wavelength theory that Campbell (1969, 1993) and Hilbert (1987) have assumed.

5.2 Colour Constancy and Retinex Theory

Other recent work has also challenged Retinex theory and Mondrians in relation to colour constancy per se. Valberg & Lange-Malecki (1990) tested colour constancy in Mondrian patterns with a matching technique. They found:

> that there is no specific Mondrian " colour constancy ". Even with a liberal definition of the term "colour constancy", much too large

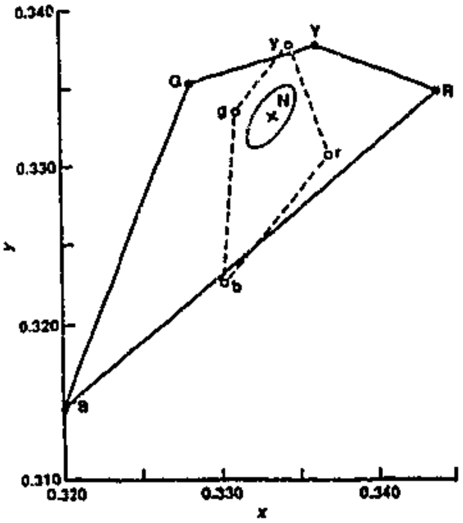


Figure 3: 1931 CIE coordinates for Mondrian displays for the blue (b,B), red (r,R) and neutral (N) test papers with identical triplets of light meter readings for 50 nm (solid line) amd 10 nm (dashed line) bandwidth spectral filter under Retinex Illumination conditions. For the 50 nm filter condition (filled circles) the " equated " papers show a total variation about 22 times the area of the nearest MacAdam ellipse. (The nearest ellipse is at (x,y) = (0.305, 0.323) but is centred at the neutral reflectance for easy visual comparison). For the 10 nm condition (open circles) the variation is less than for the 50 nm condition, but is still about eight times the area of the MacAdam ellipse. Any chromaticities outside the bounds of the MacAdam ellipse shown would be discriminable from neutral by a human. (from Young,1987)

> colour shifts occur in a typical Mondrian experiment......using exact colour matches, we confirm that contrary to Land's implications illumination changes may cause large changes in perceived colour......moreover, a complex Mondrian surround is not necessary to obtain the effects demonstrated by Land. Identical effects could be obtained when the Mondrian surround was replaced by a homogeneous grey field (p. 372).

Brainard and Wandell (1986) also present evidence against Retinex theory by showing that the Retinex algorithm is too sensitive to changes in the colour of nearby objects to serve as an adequate model of human colour constancy.

There is other evidence that produces problems for Retinex theory. For instance, Dedrick (1995) points out that:

> The problem is that retinex theory makes certain assumptions (that step-changes in what Land referred to as 'lightness values' mark borders between colours, for instance) that are false for scenes in three dimensions, in shadows and so on (p. 41).

Lennie and D'Zmura (1988) argue that there are four problem areas for Retinex theory, which make it an unlikely account of colour constancy

First, the postulated "lightness" signals are at odds with the physiological accounts of neural coding of colour, be it opponent processing or the more diverse mechanisms suggested in this thesis (e.g. the comments of Livingstone and Hubel (1984) cited above.

Second, Lennie and D'Zmura (1988) argue that:

> it has become clear that the gradual variations in intensity across a scene which result from changes in illumination present insurmountable difficulties for the simple threshold mechanisms incorporated in some algorithms (p. 386).

Third, They also say that:

> Retinex algorithms require mechanisms that accumulate lightness signals from a large region of the visual field, yet

physiological investigations show at least as far as the striate cortex, most neurones have quite circumscribed receptive fields (p. 386).

They go on to cast doubt on Zeki's claim that V4 is the place as it has much larger receptive fields. They describe Zeki's (1983) work as too informal.

Fourth, they point out that Brainard and Wandell (1986) have shown that retinex algorithims must run for a very long time before they generate a stable lightness for a particular scene (i.e. the algorithms do not converge well).

McGilvray (1983) points to another deficiency in Land's theory. He says that:

> colors are defined in terms of lightness in Land's theory, if by 'defined' one means that colors are related to lightness in the way triples of lightness map onto a color solid. "Reducing" colors to lightness on the basis of such a definition would be trivial, however; such a reduction is entirely intra-theoretic, and tells us nothing about reduction to, e.g. neurophysiology. The interesting issues are left open. They require that we must specify just what colors (or triples) "are"... that they are properties of. Land's triples of lightness values, as opposed to the constructive explanation of color suggested by the account as a whole, are not likely to yield a plausible story of what colors are. (p. 55).

While all the above considerations are difficult for Retinex theory, Campbell (1993) has changed his views somewhat on other grounds about Land's theory of reflectance and reflective realism per se. Land, like Hilbert, has argued that as the flux reaching the eye does not determine the colour, then colour judgements must be made on some information which the flux carries, but which is not itself changing when the flux changes (Land, 1977, p. 115). Surface spectral reflectance is the only stable property. Campbell (1993) points out that this explanation will only cover opaque bodies whose surfaces are seen only by reflected light. It won't cover colour produced by incandescence and other sources of direct light (Nassau, 1983).

Retinex theory depends on wavelength or cone information at one point being compared with the same information at other points distributed in the visual field.

Thus the input to each of the three cones in a patch of colour are compared with the same input across the visual field to yield the three integrated levels of brightness or the three reflectance triples. As Campbell points out none of the other sources of colour have these reflectance triples even though they produce colours that match exactly those produced by selective reflection. It is interesting to note that Livingstone and Hubel (1984) have pointed out that this model of Land would require cells excited by one wavelength in their receptive field and at the same time are inhibited in the surround of their receptive field by the same wavelength (in other words a R+, R- field). Cells of this type have not been seen.

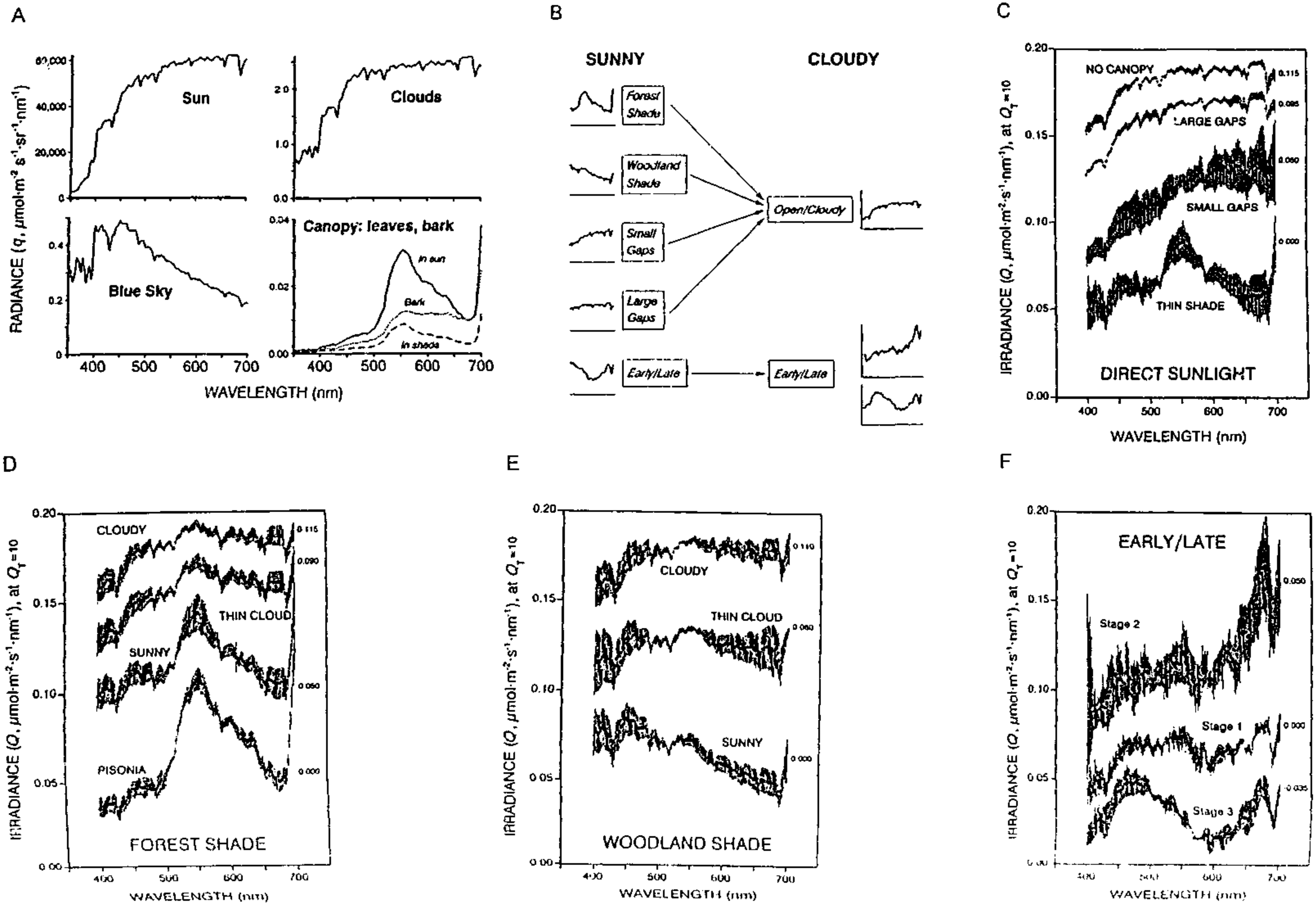
Although I wish to rule out Hilbert's Reflectance realism with its emphasis on Retinex theory and its version of colour constancy as being against wavelength theory, I realize that colour constancy per se still raises issues for wavelength theory. Colour constancy means that an object retains the same colour under changes of illuminant colour; in other words an animal is able to discount the change in the illuminant. Arend and Reeves (1986) have suggested that there might be two mechanisms underlying colour constancy: An adaptation mechanism defined in terms of temporal interactions whereby the sensitivities of the chromatic channels change over time in response to changes in the illuminant and a simultaneous mechanism defined in terms of spatial interactions. An example of this type of mechanism is simultaneous colour contrast. Arend and Reeves point out that there are extensive data showing that adaptation, alone or in combination with simultaneous mechanisms can produce large hue and contrast shifts. The problem for wavelength theory is how can changes in wavelength be still perceived as the same color. Given our emphasis on the natural colour environment and the evolution of human colour vision, what is the role of colour constancy and context in this situation?

Endler (1993) has examined how forest environments vary with natural changes in the light environment. Endler (1993) analysed the radiance spectra of the three light sources illuminating colour patterns in forests (Figure 4A). The spectrum of the sun is white but is richer in long wavelengths (redder) than that of the white produced by clouds and is many magnitudes more intense. The blue sky is richer in shorter wavelengths. Leaves in the sun reflect more light but have a similar distribution to leaves in the shade with a peak around 550 nm (Figure 4 A). Endler (1993) divides forests into five light habitats with characteristic ratios of solid angles for sun, sky and vegetation. Four of these are forest shade, woodland shade, small gaps in the canopy and large gaps (Figure 4 B).

Forests are groups of trees in which most of the crowns overlap, forming a nearly continuous canopy with very few small holes or gaps. Woodlands are groups of trees in which most of the crowns are separated leaving large as well as small gaps in the canopy. Forest shade (Figure 4 D) and small gaps receive little if any skylight, whereas woodland shade and large gaps receive much skylight (Figure 4 E). It is important to note that clouds produce a surprising change in the light in forest shade (Figure 4 D). When it is sunny there is peak in the spectrum around 550 nm and the light is yellow-green to the human eye. When there are clouds the light in the forest is white (Figure 4 D). In woodland shade, a sunny sky leads to a spectrum that is relatively rich in short wavelengths and appears bluish or bluish-gray. With clouds, the spectrum is more whitish (Figure 4 E). Clouds make little difference to the shape of the spectrum in open areas and are similar to large gaps (figure 4 C).

Endler (1993) has a fifth colour environment which he calls early / late (Figure 4 F). This is when the sun is at low angles either in the morning or at evening. There are no differences between morning and night. There are 3 stages: stage 1 is early when the sun is below 10° from the horizon; the spectrum becomes purplish-white or slightly deficient in middle-wavelengths; stage 2 occurs as the sun sets and requires clouds. A yellow-to-red light is reflected onto the forest floor. Stage 3 occurs after the sun has set. The reduction of middle wavelengths becomes more pronounced and light becomes purplish. The reduction in middle wavelengths is caused by atmospheric ozone and stage 2 by long wavelength light not being scattered in the longer distance travelled. This illuminates overhead clouds and is then reflected onto the forest floor. If there are no clouds the long wavelength light escapes into space and this stage is absent. Stages 2 and 3 can be as short as a minute or as long as 15 minutes, thus their possible role in colour constancy is possibly quite limited.

Figure 4: Reflectance spectra for the different light environments in forests and in the open. (A): spectra of the sun, clouds , blue sky and leaves in canopy during sun and shade; (B)spectra of the 5 light environments; (C) spectra of conditions recorded in direct sunlight; (D): spectra recorded in forest shade; (E): spectra recorded in woodland shade; (F): spectra recorded under early/ late conditions.(from Endler,1993).


A
Sun
Clouds
Blue Sky
Canopy: leaves, bark
in sun
Bark
in shade
RADIANCE (q, µmol·m⁻²·s⁻¹·sr⁻¹·nm⁻¹)
WAVELENGTH (nm)
B
SUNNY
CLOUDY
Forest Shade
Woodland Shade
Small Gaps
Large Gaps
Early/Late
Open/Cloudy
Early/Late
C
NO CANOPY
LARGE GAPS
SMALL GAPS
THIN SHADE
DIRECT SUNLIGHT
IRRADIANCE (Q, µmol·m⁻²·s⁻¹·nm⁻¹), at Q_T=10
WAVELENGTH (nm)
D
CLOUDY
THIN CLOUD
SUNNY
PISONIA
FOREST SHADE
E
CLOUDY
THIN CLOUD
SUNNY
WOODLAND SHADE
F
EARLY/LATE
Stage 2
Stage 1
Stage 3

Shepard (1992) has proposed another theory that trichromacy has evolved as a response to the three degrees of freedom of natural illumination. The first degree of freedom is a light-dark variation. The lightest variation is provided by an overhead sun on a clear day. The dark variation arises from a chromatically non-selective filtering when light arrives after being scattered by chromatically neutral surfaces such as white clouds, grey cliffs etc. The other variation is a yellow-blue one, which arises from Raleigh scattering of the shortest wavelengths by the smallest particles in the atmosphere. Shepard says the yellow variation occurs in direct sunlight and the blue variation occurs when some localized object blocks direct sunlight, while permitting bluer illumination from the blue sky. The red-green variation depends on the elevation of the sun and the atmospheric burden of water vapour. When there is little water vapour there is more of the red component. When there is considerable water vapour more red is absorbed so there is more green.

Shepard also claims that there is a difference between sunrise and sunset, unlike the evidence of Endler (1993). The major problem for Shepard's theory as compared with Mollon's theory of the evolution of colour is why are there so few species with trichromatic vision. His three degrees are so general in their application to natural environments that all animals exposed to them should develop trichromatic colour vision. Most mammals are cone dichromats, with a short-wavelength sensitive cone (S, blue) and a long-wavelength cone only (Jacobs, 1993) At least Mollon's theory appears to give a concise explanation of the evolution of human colour vision as arising in the forest in particular species and under specific conditions. Moreover, the theory appears to fit with Endler's measurements of illuminants and colour habitats.

Osorio (1997), using Endler's measurements of illuminations in the forest (Figure 4 A), has looked at colour constancy in the forest illumination environment. It is a pity that Osorio (1997) does not include Endler's measurements of light when there is cloud in the sky, as this produces the largest change in the forest spectrum. Osorio (1997) takes up the question of colour constancy for a frugivore in a model jungle. A uniform background of leaves gives a predictable mean reflectance, the illuminant is unknown, and target fruits of indeterminate ripeness are equiluminant with the background of leaves. This claim, of course, differs from Mollon's (1991) argument about equiluminance (see Chapter 3.0).

Osorio & Vorobyev (1996) have modelled the dichromatic and trichromatic eye and examined their usefulness for finding fruit, and for identifying fruit and leaves by colour. They find that the dichromat's eye is almost as good as a trichromat's for identification tasks, but the trichromat has an advantage for detecting fruit against a background of leaves. Under the changes in the forest illuminants, a shift of more than one jnd in the chromatic signal for the fruit against its natural leafy background is indicative of imperfect colour constancy according to Osorio (1997). Osorio shows that the residual shifts in chromatic signals due to variable illumination have the potential to degrade colour vision. Osorio, using theoretical calculations, finds that the L-M signals for ripe fruit against a background of leaves might vary by up to 3 JND's. Osorio (1997) points out that the detrimental effects of variations in illumination could be a factor in promoting the phylogenetic stability of the M and L pigments tunings. This is because the variable illumination limits the improvement in the chromatic signal given by increases in pigment separation. In general (disregarding the L-S signal), such increases will give a larger L-M signal for fruit, but this improvement may be offset by the increased failures of colour constancy.

Osorio (1997) concludes that constancy may be important for a monkey foraging for fruit in variegated light, where variation in illumination may limit the number of discriminable stages of fruit ripeness. Osorio also argues that neither information criteria nor the need to reconstruct reflectance (or illumination) spectra suffice to explain the tuning of the cone pigments:

> the stability of the pigment tuning indicates that the red-green signal rather than being a general source of visual information, is an adaptation for finding food which compromises luminance based vision (p. 488).

Osorio says that:

one inference from this observation is that cone peaks have been selected so as to minimize chromatic interference in the luminance signal, while at the same time maintaining a good L-M signal from the special colours of fruit. (p. 484).

It is unfortunate that Osorio's theory depends on modelling the eyes and not on direct testing of old world monkeys (*Catarrhines)* in the different colour environments, an almost impossible task no doubt!

The main conclusion is that the light spectra in the forest shade, in which our colour vision evolved, do not produce strong conditions involving the need for consistent colour constancy. The failure of good colour constancy appears to maintain the existing separation of the L and M pigments. Osorio and Vorobyev (1996) argue that:

Such failures, which increase with increasing spectral separation of the photopigments, reduce the reliability of chromatic cues for identification (p. 598).

Thus changes in wavelength in the illuminant are important factors in the canopy for colour. If one looks carefully at Endler's measurements, it is clear that the main change in the light environment occurs in forest shade when there is cloud (Figure 4 A, F). In cloudy conditions, the spectrum no longer peaks around 550nm and changes to a white spectrum. This change should not effect the perception of coloured fruit, because as Helson and Jeffers (1940) showed, colours tend to keep their daylight colour if the changed illuminant still contains their dominant wavelength and which is present even as a minor component in the illuminant.

Arend and Reeves (1986) have argued that:

the paper that looks unique yellow under direct sunlight might look greenish yellow under a tree and yet might be clearly identifiable as a yellow paper (p. 1749).

Thus it would seem that the perception of yellow fruit and green leaves would not change greatly under most of the other illuminants in the forest. Endler's early / late stages produce more dramatic changes (Figure 4 F), but they mostly increase the yellowish and reddish light. This should not make it more difficult to see the fruit. Also early morning and late evening is not a time of great eating activity in either howler monkeys (Smith, 1977) or macaques (Lindburg, 1977). Thus there would be limited opportunities at these times for evolutionary pressure on the visual system.

It is clear that wavelength realism needs to be considered in a visual context in a manner somewhat like Hilbert's anthropocentric approach, or that of Averill (1982), or Jackson's (1996) anthropocentric sense tied to normal humans in normal circumstances (p 205-206), (i.e. the conditions of the subjects visual system should be considered). This is necessitated by the apparent role of context (Valberg and Lange-Malecki, 1990) and the particular conditions for colour constancy in a forest setting.

CHAPTER 6.0

6.1 Adaptation

Another contextual problem involves the role of adaptation in colour vision. Campbell (1969) has argued that adaptation is the most pervasive condition determining what colour is seen, i.e. the most stimulated parts of the visual system become relatively less sensitive. Thus there is variability in colour appearance of unchanging objects in unchanging lights. Campbell (1969) concludes:

> that colours are not properties or powers of objects or of lights considered in isolation from the perceiving of them (p143).

Campbell (1969) proposes that there can be either transitory or standing colours. Transitory colours are those which change due to either changes in illumination or to adaptation changes. Standing colour is a permanent property of surfaces and can be accounted for in terms of transitory ones. Campbell (1969) argues that: we can never know what the real colour is, because we would have to specify some adaptive condition as standard. Campbell (1969), however, says that:

> to insist that the circumstances leading to one adaptive state enable us to see colour aright, while all others turn vision awry, is to be partial beyond reason. It involves determining the real colour of a surface (which is supposed to be an objective, physical, property) on grounds totally remote from the physical circumstances of the surfaces (e.g. that it looks magneta to normal eyes after exposure to room sunlight, although not otherwise) ....The essence of this objection is this; the real colour cannot be determined by appealing to standard conditions of observation unless these conditions include a specification of the observers adaptive state. But then the real colour cannot be accorded any ontological pre-eminence over its rivals. For nothing in rebus distinguishes the "real" red from the "merely apparent" purple or vice versa (p.146).

The adaptation problem highlights the role of standard conditions in analysing the concept of colour. There does seem to be a difference between primary qualities and secondary qualities in this regard. For example, a square looks square because it is square. We can measure it and also feel it and not depend on how it looks. We don't approach the perception of shape by standard conditions. We don't need to take into account the adaptation condition of the observer. Although, there is evidence that the orientation of shapes can be influenced by adaptation and by spatial illusions. With colour, however, something looks green because it has such and such surface properties. That is, it is equally real as shape, but we solely depend on vision leading to their saliency for us. Thus the adaptive condition of the observer is important for judgments of colour.

This adaptation argument presents real problems for any wavelength theory of colour. It highlights that any explanation of colour will have to be anthropocentric in structure, in other words, the condition of the subject, as well as the physical object, will have to be taken into account. We can ask the same question about adaptation that we have confronted with the other objections. What is the evidence about adaptation in the natural environment? Webster (1996), in an extensive review of adaptation and human colour perception, points out that there have been few measurements of the colour statistics of natural images and virtually no work on adaptation and natural images, apart from some recent work from his laboratory (Webster et al., 1996; Webster & Mollon, 1997). Measurements were taken of natural scenes using two procedures: (1) a spectroradiometer which analysed a grid of 45° x 45° of space; (2) a monochrome digital camera in conjunction with 31 interference filters. (Webster & Mollon, 1997).

Using an asymmetric matching technique, they found adaptation effects or an alteration in colour appearance with stimuli derived from these procedures, which could be explained by two stages or processes: an initial stage of light adaptation of the von Kries type and followed by contrast adaptation. They concluded that despite the highly restricted colour distributions characterizing natural images, there were strongly selective changes in colour appearance which could arise when the same scene is viewed under changes in illumination (e.g. weather or changes in the seasons). They did not use images from forest canopies, so the implications might be limited for these situations. In fact, in one of their papers on this topic (Webster, Wade & Mollon, 1996), they conclude that:

> adaptation has a proportionally weaker effect on higher contrast stimuli, and even after days in a wood the perception of a dominant color axis seems to persist (p. 151).

Arend (1993) looked at adaptation to three daylight spectra: 4000K or reddish light just after dawn; 6,500K or average daylight; and 10,000K or northern hemisphere daylight. He found changes in the CIE co-ordinates for the unique hues, when the adaptation conditions changed. Even so, Arend concludes that:

> invariance of apparent surface colour seems to occur in some natural scenes with chromatic shading (skylight versus skylight plus direct sunlight) (p. 2146).

Moreover, as we noted above the perception of yellow would not be changed too much under changes in canopy conditions, so adaptation would not play such a vital role. Overall, it can be concluded that adaptation and colour constancy don't present problems for wavelength theory in canopy conditions in which our colour system evolved.

It should be stressed that Webster and Mollon did not analyse colour forest conditions separately in their adaptation stimuli. This raises the issue of just how we can determine what the standard colour of an object is in natural conditions? Hardin (1983, 1988) has discussed standard conditions and normal observers. He points out that there are problems with specifying both these conditions. Context effects, such as with the colours brown and olive green:

> demonstrate that any attempt to identify the colors of objects with spectral emittance or reflectance will do violence to established color concepts (p808).

This is because colours like brown depend on the surrounding brightness level to appear brown, even though the same spectral wavelengths are emitted as those of yellow; in other words brown is a darkened yellow. The problem with normal observers is compounded by adaptation state and differences in colour sensitivity between people. With regard to colours in the natural environment, it would seem appropriate to us to use a scheme such the 1931 CIE (Commission Internationale de l'Éclairage) classification to describe standard colours for natural coloured images. Webster and Mollon (1997); Hendley and Hecht (1949); Burton and Moorhead (1987) and Arend (1993) all measured natural colour stimuli and translated the measurements into CIE co-ordinates. In Figure 5, Hendley and Hecht (1949) show the range of natural colours in a CIE tristimulus diagram. Like Osorio and Bossomaier (1992), they found three major groups of colour: green plants in a yellow-green region varying from 550mnm to 575 nm in dominant wavelength; earths and dried vegetation which are yellow to orange-red (576 to 589 nm) and water, sky and distant objects are blue (459 to 486 nm). It should be stressed that very few colours were found outside these groups. It should also be stressed that the measurements were taken of terrains seen from some distance. Highly saturated cultivated objects, especially flowers, were not considered as they influence vision only at short ranges (e.g., < 0.5 km).

Of course, Osorio and Bossomaier (1992) concentrated on the colours of flowers close up, in keeping with their theory of the evolution of colour vision with frugivorous monkeys. However, over all, there is a limited range of colour in natural objects compared with the possible range of colours when plotted in a uniform chromaticity diagram (Figure 5). Thus, the issue becomes whether we are justified in evoking the CIE measure as the standard colour? It is clear that the 1931 CIE values were determined under precise conditions: a 2° viewing field; the colour matches apply only to a hypothetical standard observer and are valid only for restricted conditions of viewing with small fields, that are neither too bright nor too dim (Kaiser and Boynton, 1996, p 25). The small field should not be much of a problem as the 1964 CIE diagram based on a 10° annulus field yielded data that was largely similar to 1931 except for differences in the blue-green (Kaiser & Boynton, 1996, p. 541). The main virtue of using these diagrams is that measurements can be obtained with equipment without using observers. It is true that the tristimulus values of colour do not correspond to perceptual colour, i.e. the CIE system is not for specifying colour appearance but for specifying difference or

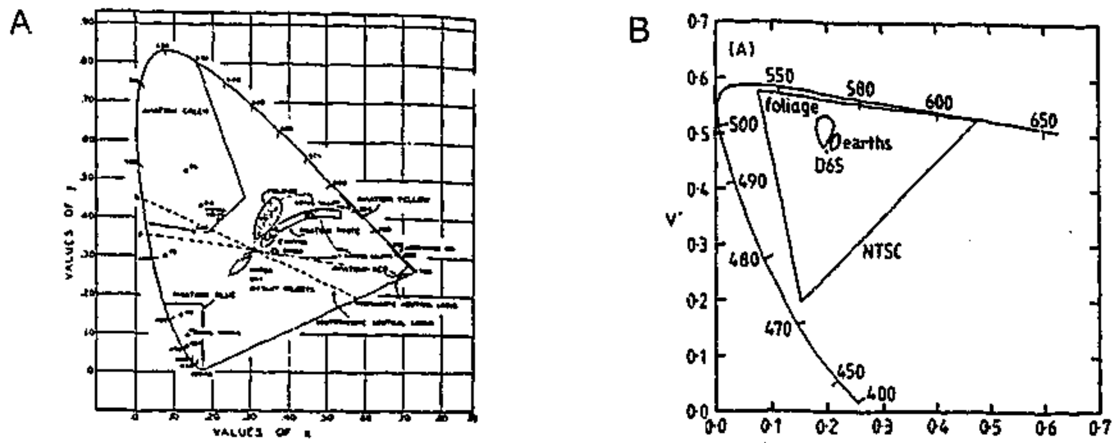


Figure 5: A: 1931 CIE coordinates of natural stimuli showing the position of colours of foliage, earth and brick and water, sky and distant objects. The position of strong artificial colours e.g., aviation green, blue and red are shown. Neutral lines for dichromats are also shown (from Hendley & Hecht,1949). B: Replotting of the Hendley & Hecht (1949) data in 1976 CIE coordinates showing the spectrum locus of foliage and earths (the small closed curves adjacent to the daylight poinr, D65). The small extent of the colours is shown by comparison with the colour gambit for the NTSC colour TV standard (large triangle). Note the large difference between the range occupied by distant terrain scenes and that required in man-made environments. (from Burton & Moorhead, 1987).

equivalence of light stimuli (Kaiser & Boynton, 1996, p 545). Thus measurements such as those taken by Hendley & Hecht (1949); Burton & Moorhead (1987); Webster & Mollon (1997) will indicate if the light has wavelengths that are green and will match across conditions, independently of particular observers and their adaptation status. The fact that such measurements of colour can be made should indicate that colour is a primary property.

Campbell (1972) argued that if one could measure a quality, then it would be a primary quality, not a secondary one. He did not think that colour had reached this stage:

> The claim that a quality is primary, in our ontic interpretation, is a substantial claim concerning the nature of the material.... our criterion identifies as primary all for which there is a distinctive interaction pattern. The range of primary qualities is thus a very wide one. It includes every quality for which we can devise a meter or detecting instrument ... the class of secondary qualities seems doomed to a career of declining membership, with instrumental investigation of warmth and sound an accomplished fact, work on smell proceeding, and only taste and colour, so far as I know, remaining resolutely secondary (p. 226).

It would seem that instrumental measurements of CIE tristimulus values meet this criterion. It is acknowledged that the measures are based on a standard observer, but they are not meant to indicate what particular colour a person will see. Instead, they indicate the general colour that will be produced by three wavelengths. Thus in the above measures of natural stimuli, if they have the same tristimulus values, then the colours will match, no matter what is the exact colour reported by any observer. Thus the instrument will indicate colours such as green or red or yellow quite precisely on each occasion of measurement, independently of any observer. If one is carrying out a colour experiment and one gives the CIE co-ordinates of your stimuli, then other research workers can use the same colour stimuli. This seems to meet Campbell's requirements about a meter.

Overall, I think that the evidence suggests that adaptation is not a big factor in the forest conditions, based on the suggestions of Webster and Mollon (1997) and

Arend (1993). While adaptation is obviously an important factor under many visual conditions, it does not have such an important role where our colour system evolved.

CHAPTER 7.0

7.1 Wavelength and Illusions.

As we mentioned earlier, Campbell (1993) reluctantly suggests that subjectivism about colour might be the answer to the basis of colour rather than an external reality like wavelength. Campbell (1993) claims that a necessary condition for any subjectivist account of colour is that in the absence of observers with colour vision, there would be no colours in the world.. He stresses that all forms of subjectivism are projectivist. We project greeness onto the cause of looking-green. Thus subjective theories are all error theories. Campbell (1993) argues that:

> Reductionism will succeed only if it can banish qualia. And qualia refuse to go away. This puts us between a rock and a hard place. Dualism and reductionism seem equally unacceptable (p. 266).

Campbell reluctantly indicates this might lead to a full-scale srror theory in which no colour is a physical property of the environment and:

> no sense data__ or visual patches understood as psychological states of perceivers__ are coloured either. (p. 267).

Campbell regards this overall position as a desperation option, but Campbell (1993) cites a number of conditions that support subjectivism. He cites the effects of simultaneous contrast as an example of a subjective or at least a relational determinant of colour. Other effects are considered examples of subjective colours e.g.: after images, coloured shadows, colours from moving black and white stimuli and the filling-in process (Larimer and Piantanida, 1988). These effects are often classified as subjective qualia or sense data.

Hardin (1993) uses these types of subjective colour effects to attack wavelength realism (Armstrong, 1993), reflectance realism (Hilbert, 1987) and Smart's (1995) version of colour dispositions and to support his theory that colour is a subjective neural process that is projected onto objects in the world.

There is also another Australian approach to images, qualia and sense data. Smart (1995) argues that:

> Neither sense data nor images are part of the furniture of the world. The having of a red mental image is having an inner going on which is like what goes on when we have (say) a ripe tomato before our eyes..... Nevertheless I hold that imaging has a fundamental similarity to seeing: in imagining we are putting ourselves through similar sorts of motions, which I hold to be processes in the brain of which we are not aware as brain processes but only topic neutrally (p. 550).

It could be asked how this topic neutral approach differs from Hardin's neural subjectivism. Unlike Hardin, Smart thinks that colours are out in the world not in the brain. He says:

> if there are no sense data (but only the havings of them) then there are no red, square or round sense data, only the experiences, the havings of them, and these are not red, round or square (p. 551).

Armstrong in Armstrong and Malcolm (1984) also supports a topic neutral approach in his causal theory of mind. He says that:

> It is true that the causal theory of mind does lead naturally to a materialist theory of mind. For suppose that we consider all the outward physical behaviour of human beings, and other higher animals, which we take to be mind-betokening. In the light of our current knowledge, it seems quite likely that the sole causes of this behaviour are external stimuli together with internal physiological processes, in particular physiological processes in the central nervous system, but if we accept this premise on grounds of general scientific plausibility, and also accept the causal theory of mind, the mental must in fact be physiological. Formally, however, the causal theory is a 'topic-neutral' theory, because it does not specify the nature of that which plays the causal role. This seems to correspond with our experience of the mental. It is often said that the mental, as we actually experience it introspectively, is elusive, hard to pin down, as it were transparent or diaphanous. The causal theory can explain these

> phenomenological reports as a somewhat distorted recognition of the topic-neutral nature of our knowledge of mental phenomena. What is grasped only as something which plays a certain causal role is grasped transparently and inconclusively. (p. 157-158).

Both Smart and Armstrong deny that there are things like after-images. Armstrong in Armstrong and Malcolm (1984) says that:

> I wish to deny that there are such things as after-images. To have an after-image is to seem to see a physical phenomenon of a certain sort: the after-image itself, I maintain, is a purely intentional object (p. 130).

The topic-neutral approach has been heavily criticized by a number of philosophers (Bradley, 1964; Jackson, 1977; Rosenthal, 1976; Kripke, 1980; Lund,1994). Rosenthal (1976) argues that the topic neutral translation of Smart and Armstrong has tried to address what he calls the 'irreducibly psychic properties' (IPP) objection to materialism. Rosenthal claims that their approach is a semantic one, when a reductive approach might be needed. However, there has been no systematic attempt in either the philosophy or the physiology literature to see whether visual science supports a reductive approach to such mental properties. Let us look at the various 'subjective' effects to see if they can be encompassed in terms of a reductive approach to topic-neutrality.

7.2 Afterimages

Some experiments support the topic-neutral concept of Smart and Armstrong in that these experiments have shown that the mechanisms underlying AI's can act like external stimuli. Day and Webster (1989) used an AI combined with an external stimulus (a black and white grating) to produce a McCollough after-effect. A uniform red stimulus was presented followed by a vertical black and white grating, thus a green AI was on the grating. This was followed by a green stimulus followed by a horizontal black and white grating, producing a red AI on the grating. After a sequence of these alternations, a coloured red after-effect was produced on a vertical black and white grating and a green after-effect was produced on a black and white horizontal grating. This McCollough after-effect is not an AI (Day and Webster, 1989). If the colours had been presented simultaneously with the gratings, then the after-effects would be reversed with a green one on the vertical grating and a red one on the horizontal. Instead an AI was present with the gratings during adaptation and acted like a coloured external stimulus in producing after-effects opposite in colour to those of the simultaneous presentation. Thus the mechanism underlying AI's can act like a real colour mechanism and get hooked up to an external stimulus to produce an after-effect. Anstis et al. (1978) also showed that AI's could get hooked up to an external stimulus. The details of this will be given in the next section on simultaneous colour contrast

7.3 Simultaneous Colour Contrast.

Hardin (1993) and Campbell (1993) have argued that the colours produced by simultaneous contrast cannot be explained by external realistic accounts. Both claim that the unity of colours lies in the unity of the responses engendered in creatures with a colour system like ours. It does not reside in any extra-animate physical reality (Campbell, 1993, p. 257). However, a case can be made for regarding simultaneous contrast to be related to a wavelength explanation. Simultaneous contrast occurs when light of a certain wavelength strikes an area that surrounds another area which is either achromatic or of a different colour. It then produces a change in colour in the surrounded area. For example, when a grey spot is surrounded by a green area, the grey spot appears to take on a reddish colour.

Anstis et al. (1978) have shown that the colour of the simultaneous contrast can act like an external stimulus and produce an AI. In the case of the grey spot surrounded by green, there will be produced a red colour in the spot. But this red colour will induce now a green AI in the grey spot. That is, subjective simultaneous contrast colours can produce their own AI's. They also showed by clever experiments that the AI produced by the surround will also induce simultaneous colour contrast in the spot. Thus once again we have an AI acting like an external stimulus. Similar explanations apply to the case of coloured shadows. We would argue that in both the cases of AI's and simultaneous contrast colours we have mechanisms operating in the same way as when there are colours present before us. Clark (1985) argues that psychophysiological explanations make the gray patch surrounded by green to be indiscriminable from a reddish patch. However, Clark prefers to argue for qualia playing a role (i.e. a representationalist claim). He contrasts this with a direct realist claim that the immediate object of perception is always some physical object (or state or event) which is situated before the sense organ. We prefer the direct realist topic neutral account of simultaneous contrast, in that it acts as though an external stimulus is present..

The physiological explanation of simultaneous contrast is not clear cut, because it can occur over quite large areas, whereas most neurones signalling information about the center of the visual field are quite uninfluenced by stimuli even 1° away (DeValois & DeValois, 1997, p. 132). It is possible that extrastriate areas, such as V4, could mediate these effects as they have large receptive fields (RF) with even larger surround areas. It is clear that wavelength theory needs something like this proposed account of simultaneous contrast, perhaps combined in relation to Jackson's (1996) anthropocentric paradigm.

7.4 Stabilized Image Studies.

Larimer and Piantanida (1988) changed the colour of areas by manipulating stabilized images with a complex visual apparatus. They produced filling-in of coloured areas by other colours by stabilization on the retina. For example, a green circle was surrounded by a red annulus. When the green circle and its border between the red annulus were stabilized, then the red colour of the surround filled-in and replaced the green, even though green light was still coming off the area. By stabilizing the surround and its external border, the green of the circle replaced the red of the surround. The neural basis of this dramatic effect is not known, but it can be shown that the filled-in colour acts like an external colour, by interacting with an unstabilized colour placed on top of the stabilized area (Larimer and Piantanida, 1988). Thus, this filling-in effect acts like a mechanism or process in the brain as though a colour is present. That is, the filling-in mechanism is capable of modifying the colour of regions that are viewed normally, in unstabilized vision. By stabilizing the boundary between a red stripe and a green stripe, Larimer and Piantanida (1988) and Crane and Piantanida (1983) also produced colours never seen before e.g. reddish green and yellowish blue. They conclude that the most central cortical representation of perceived colour is not an opponent process, thus supporting our earlier arguments. These filling-in processes can also be given a topic neutral account by a mechanism that involves the stabilization of the boundaries enclosing a coloured area. These filling-in mechanisms also cover large areas like simultaneous contrast (Larimer and Piantanida, 1988) and thus a mechanism needs to be found for these effects, otherwise they will present difficulties for any theory of colour.

7.5 Achromatic Colours

Hardin (1993) argues that achromatic colours are difficult for any objective theory. These colours are produced by intermittent achromatic stimuli, either moving (Benham, 1894) or stationary (Butterfield, 1968; Jarvis, 1977). These effects have been shown by Brady (1954) to act like real colours as they can act as conditioned stimuli for galvanic skin responses. That is, responses conditioned to external coloured stimuli can be evoked by similar colours induced by intermittent achromatic stimuli. Thus, there is something going on like that which occurs when a real colour is presented.

7.6 Complementary Whites.

Complementary whites can be produced by combining two monochromatic lights. Newton failed to produce complementary whites and declared them impossible (Kaiser and Boynton, 1996). However, it needed very narrow spectral bands to achieve this, which were not available to Newton. It is clear that such complementary whites have no physical basis in nature. But they do not occur in the natural world and even when they are produced they have characteristics that fit our wavelength model. For example, Le Grand (1968) points out that the most efficient complementary white (for complementary pairs of 450 and 569 mμ) is unsuitable for lighting in the natural world, because of the absence of long wavelengths. Thus, red objects would appear brownish under such light. It can be concluded that all complementary whites would not occur under natural conditions and would not play a role in colour evolution. Jameson and D'Andrade (1997) point out a difficulty for opponent processes with complementary colours. Both unique green and unique red has zero output on the Y/B channel, yet when paired they yeild yellow rather than white. A bluish-green is complementary of red instead of green. Maffi and Hardin (1997) try to explain this discrepancy by arguing that the Y/B channel is non-linear, but it still appears a difficulty for Hering's classical theory

Overall, I would argue that all these examples of phenomenal individuals are illusions, which can be explained by neural mechanisms, that are normally activated when coloured stimuli are present before the animal. I feel that this approach allows a reasonable answer to Campbell's worries that they could lead to subjectivism. I don't agree that they are qualia or sense data, which are subjective phenomena. I agree with Lycan (1987) who says "If there (really) are phenomenal individuals such as sense data, then materialism is false right there " (p.18). It is important to realize that most of these illusions, apart from simultaneous contrast and AI's, will not occur in nature. Thus they would not influence the evolution of colour vision. It should also be noted that Daw (1962) has shown that AI's don't appear to be perceived under the conditions in the normal environment. This is due to the combination of short fixation times and normal contours in the world inhibiting the AI.

CHAPTER 8.0

8.1 Microphysical Bases of Colour.

Nassau (1983) has listed 15 different microphysical mechanisms underlying colour. (Table 1.1). Nassau (1983) points out that 14 of these categories all involve the excitation of electrons, in situations involving the selective absorption and emission of light, as well as its reflection, deflection, and scattering. Nassau (1980) asserts that even in the cases of items 12-15 of Table1.1 (Geometrical and Physical Optics) there is involvement of electrons in which the interaction of light with matter produces a change in direction of the light. He says:

At the most fundamental level these processes can be understood in terms of electronic excitations in matter.... (but) an analysis of this kind is always possible, but it is often too cumbersome to be very informative. What is needed is a ' higher level' analysis; it is provided by the methods of geometrical and physical optics (Nassau, 1980, p. 121).

In this context, Nassau (1983) points out that:

> When we perceive a ray of light, be it from a nearby lamp or from a distant star, it is easy to assume that the photon that stimulates the eye originated from the light-emitting object. This, however, is true only for the passage of light through a vacuum. When a uniform, nonabsorbing medium, such as he atmosphere, a sheet of glass, or a crystal of salt transmits a ray of light, the incoming photons are absorbed and immediately re-emitted in turn by all the atoms in the path of the ray. The result is a slowing down of light.... except at normal incidence, this slowing down produces a bending of the ray at an interface (p. 207).

Category 3 of Table 1.1 is different in that it involves atomic or molecular vibrations and rotations. Nassau (1983) comments that it is remarkable that so many distinct causes of colour should apply to the small band of electromagnetic radiation to which the eye is sensitive (400-700 nm, less than an octave). This is

Table 1-1. Examples of the Fifteen Causes of Color

Vibrations and Simple Excitations

1. *Incandescence*: Flames, lamps, carbon arc, limelight
2. *Gas Excitations*: Vapor lamps, lightning, auroras, some lasers
3. *Vibrations and Rotations*: Water, ice, iodine, blue gas flame

Transitions Involving Ligand Field Effects

4. *Transition Metal Compounds*: Turquoise, many pigments, some fluorescence, lasers, and phosphors
5. *Transition Metal Impurities*: Ruby, emerald, red iron ore, som fluorescence and lasers

Transitions between Molecular Orbitals

6. *Organic Compounds*: Most dyes, most biological colorations, some fluorescence and lasers
7. *Charge Transfer*: Blue sapphire, magnetite, lapis lazuli, many pigments

Transitions Involving Energy Bands

8. *Metals*: Copper, silver, gold, iron, brass, "ruby" glass
9. *Pure Semiconductors*: Silicon, galena, cinnabar, diamond
10. *Doped or Activated Semiconductors*: Blue and yellow diamond, light-emitting diodes, some lasers and phosphors
11. *Color Centers*: Amethyst, smoky quartz, desert "amethyst" glass, some fluorescence and lasers

Geometrical and Physical Optics

12. *Dispersive Refraction, Polarization, etc*: Rainbow, halos, sun dogs, green flash of sun, "fire" in gemstones
13. *Scattering*: Blue sky, red sunset, blue moon, moonstone, Raman scattering, blue eyes and some other biological colors
14. *Interference*: Oil slick on water, soap bubbles, coating on camera lenses, some biological colors
15. *Diffraction*: Aureole, glory, diffraction gratings, opal, some biological colors, most liquid crystals

because this band is the region where the interaction of radiation with electrons first becomes important. Longer wavelengths and lower energies induce small motions of atoms and molecules, which we sense as heat, if at all. Shorter wavelengths and higher energies have a destructive effect, since they can ionize atoms, that is completely remove one or more electrons, and can permanently damage molecules. Nassau (1983) says that:

> Only in the narrow optical region, just that region to which the eye is sensitive, is the energy of light well attuned to the electronic structure of matter with its wide diversity of colorful interactions (p. 24).

However, what is not emphasized is the fact that these mechanisms all change the energy and its associated wavelength of light in producing colour. In fact, it is the energy of the photon which is important in the interaction with electrons for the production of colour (Nassau, 1983). [4] (Figure 6). Nassau (1980) puts it very precisely that:

> An important constraint on all interactions of electromagnetic radiation with matter is the quantum-mechanical rule that says atoms can have only certain discrete states, each with a precisely defined, energy; intermediate energies are forbidden. Each atom has a lowest-possible energy, called the ground state, and a range of excited states of higher energy. The allowed energy states can be likened to the rungs of a ladder, although their spacing is highly irregular. Light or other radiation can be absorbed only if it carries precisely the right amount of energy to promote an atom from one rung to a higher rung. Similarly, when an atom falls from an excited state to a lower-lying one, it must emit radiation that will carry off the difference in energy between the two levels. The energy appears as a photon, or quantum of light, whose frequency and wavelength are determined by the energy difference (p. 106). (Figure 7).

This can be clearly seen in the case of the sodium atom. If one attempts to give extra energy to this atom by exciting it with either electricity or illuminating it with light, then the smallest amount of energy it can absorb is a little over 2eV. If light of this energy is absorbed, then the outmost electron excited to the next

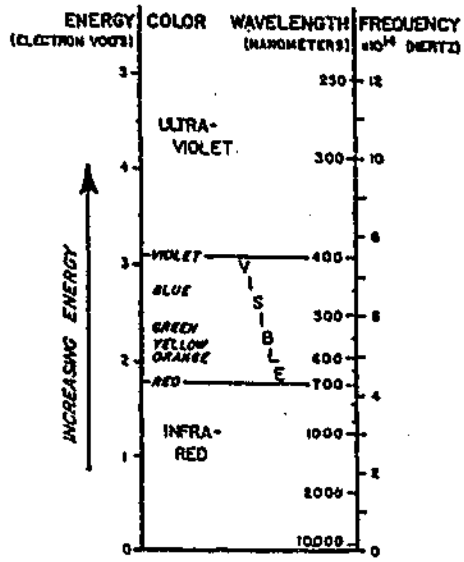


Figure 6: The three ways of measuring colour e.g.: photon energy, wavelength, and frequency. Note photon energy is inversely related to wavelength, in that shorter wavelengths have higher energies. (from Nassau, 1983).

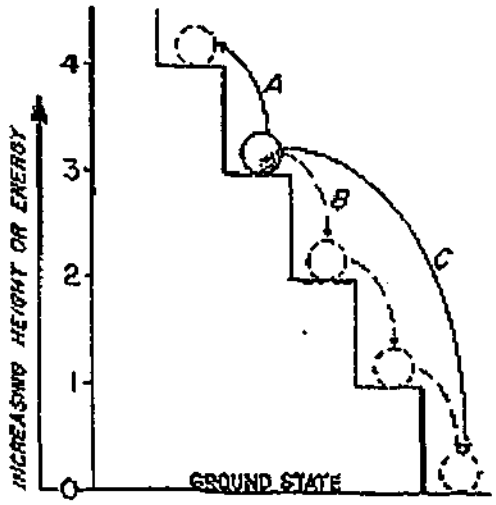


Figure 7: Schematic figure showing the discrete quantum energy levels above the ground state for photon energy interaction. Notice that the return to the ground state can be by single steps(e. g. A & B), or there could be forbidden transitions so that there is a jump to ground state(e. g., C). (from Nassau,1983).

higher energy state (e.g. $3P_{1/2}$ & $3P_{3/2}$) see Figure 8. Shortly after the electron has reached either of these two excited states, it will drop back to the ground state ($3S_{1/2}$, Figure 8). Depending on the excited level from which the electron descends, it will give out light of exactly 2.103 or 2.105 eV. These energies correspond to the famous yellow sodium doublet emission at 589.6 and 589.0 nm. (Figure 8).

While the data on sodium indicates a very precise spectral relationship with colour, this is not true about most coloured objects. This is because;

> there are three quantized molecular processes....a change in the rotational state of a molecule, a change in its vibrational state or an electronic transition....absorb energy from incident light (Maloney, 1986, p. 1678).

Maloney points out that:

> an electronic transition whose energy corresponds to a wavelength near the visible is the center of an absorption peak broadened by other transitions and smoothed by other molecular interactions in the liquid or solid state. A molecule's absorption spectrum can be described as a discrete structure of electronic transitions surrounded by vibrational transitions in turn surrounded by rotational transitions that has been passed through an approximate low-pass filter (p.1678).

Thus quite complex mechanisms are behind the broad frequency pattern of coloured objects

Now Nassau (1983) has discussed each of these mechanisms (particularly the transitions of electrons), but he did not discuss their relationships in detail. Maloney has pointed out that most spectral bands were broad and not like sodium. He says that:

> Two phenomena contribute to the broadband character of spectral absorption bands: (1) interactions among rotational, vibrational and electronic transitions and (2) molecular interactions. In molecules, the three

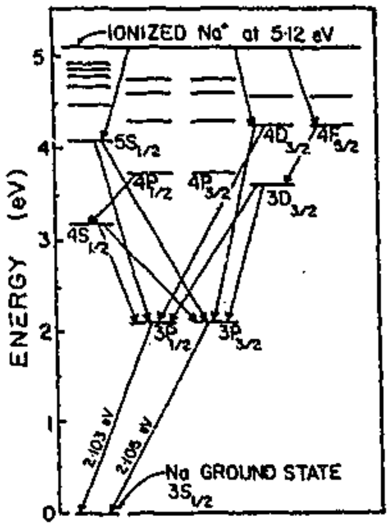


Figure 8: Energy level scheme for an atom of sodium after stimulation with white light, showing some of the allowed transitions. The final transitions are through $3P_{1/2}$ and $3P_{3/2}$, which produce photons of 2.103 eV and 2.105 eV and hence leads to the yellow sodium doublet emission of light of 589.6 and 589.0 nm (from Nassau,1983).

energy absorbing processes (vibrational, rotational, electronic) do not occur in isolation: they interact (Maloney, 1986, p. 1678).

Kauzmann (1967) argued that: (1986) has pointed out that most spectral bands were broad and not like sodium. He says that:

> strong interactions with solvents and with vibrational modes are responsible for the broad absorption bands observed in all organic compounds and in many organic compounds in solution (p. 670).

Maloney (1986) has pointed out that the half-width of a typical absorption band is approximately one half of the visible spectrum. This broad tuning supports our notion that metamers (i.e. multiple peaks) don't occur in nature, as Maloney (1986) concludes there would be at most two peaks across a smooth broad visible spectrum of reflected light. Kauzmann (1957) points out that this broad absorption spectrum need not have the peak of absorption in the visible range. He says:

> that the colors of many substances, especially those of yellowish or brownish tint, are caused by absorption bands whose peaks are in the near ultra-violet, but whose edges extend into the visible. (p. 671).

The spectra of these substances are broad.

Tolliver (1994) and Akins and Hahn (2000) criticize realist theories of colour on the basis of Nassau's categories. They claim that there is no relationship between the microstructural properties and the relations among colours. Tolliver (1994) points out that red and green are about as dissimilar as colours get. So he would expect a corresponding microstructural dissimilarity. For example, Ruby is red and emerald is green. Both consist of the same basic materials that are colourless and they get their colour from impurities in their crystal lattice. There is the same impurity (Chromium) in each case. Ions of chromium replace aluminium in a very small percentage of locations in each crystal. In each crystal, the chromium ions are surrounded by six oxygen ions in an octahedral configuration. (Figure 9). The main difference between the two crystals is in the ionic character of the chemical bonds between the chromium ions and the

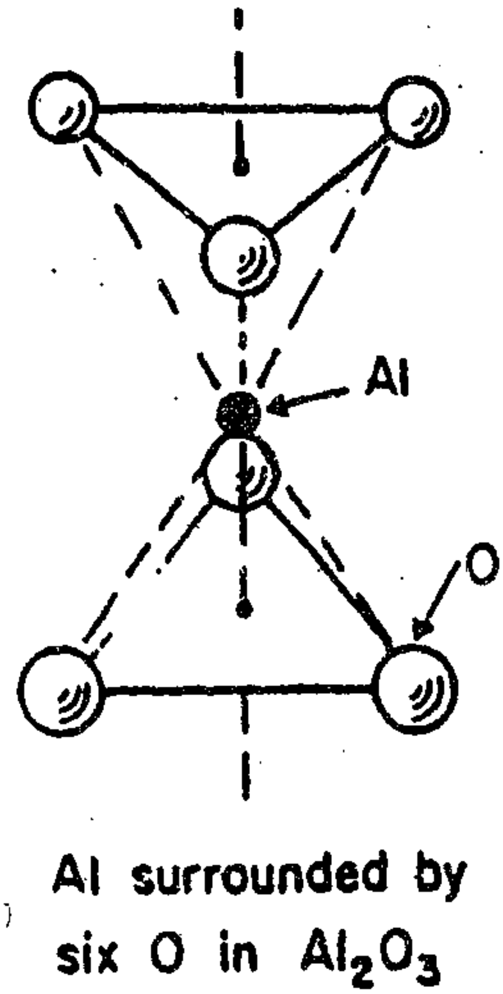


Figure 9: The distorted octahedral oxygen ligand environment around an Al ion in corundum Al_2O_3.

surrounding oxygen ions. This results in differences of the time that there are shared electrons in orbitals and differences in the ligand electrical field. This makes for differences in the energy needed to lift electrons to another energy level (Nassau, 1983). Consequently, ruby and emerald differ in their pattern of spectral absorption, which is based on the energy characteristics of the photons striking the crystals. This means they differ in the wavelength of light they absorb. In Figure 10, the absorption of light for ruby is shown. In Figure 10 A & B, the ligand fields vary with the energy of the photon. Light of 2.2 eV takes chromium from the $^4A_2$ ground level to the $^4T_2$ excited level. Light of 3.0 eV takes it to the $^4T_1$ level. These levels lead to absorption in violet and green / yellow (Figure 10 C). There is small blue transmission and strong red transmission leading to the red colour of ruby. The selection rules do not allow a return from these states directly to ground level, but do allow transition to an intermediate level ^2E. The return from ^2E is permitted and this leads to a photon release of 1.79 eV ,which produces a red fluorescence (Figure 10 C). Similar effects are seen with emerald (Figure 11 A, B, C) with there being violet and yellow/red absorption and strong blue green transmission leading to emeralds green colour. The small red fluorescence adds to the quality of the green colour in exceptionally pure emeralds. (Nassau, 1983).

Tolliver (1994) points out that the microstructural and spectral differences are quite small, yet ruby and emerald differ in color as much as any two things can . . Tolliver concludes that the differences in microstructure have no pattern of resemblance to the patterns of similarity and differences among the colours. However, the essential point is that the microstructures lead to differences in wavelength reflected and hence to differences in colour. (Figure 10 &11). In fact, most of Nassau's categories lead to changes in wavelength by interaction with electrons. Thus colour is not identical with any of its microstructural properties, but is related to the wavelengths produced by the microstructural bases. Thus one need not worry about any disjunctive classification of microstructural causes of colour, it is the wavelengths produced that are critical [5].

It is interesting to contemplate the interaction of photon energy with electrons. It might be possible to suggest that colour does have a role in the

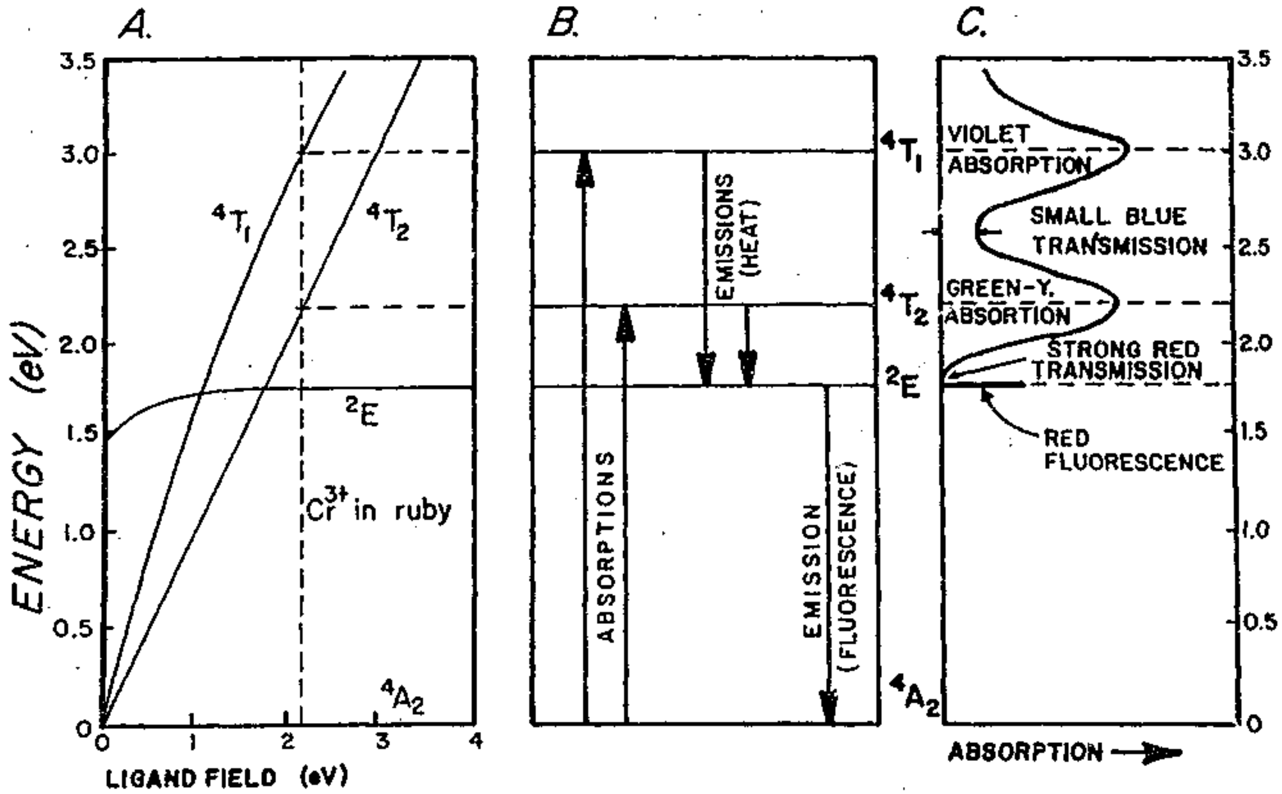


Figure 10: The absorptions and emissions of chromium (Cr^{3+}) in a distorted octahedral ligand field of ruby. A: Two absorption mechanisms when white light passes through ruby. Light of 2.3 eV can be absorbed to take take chromium from $^4A_2$ ground level to the $^4T_2$ excited level and 3.0 eV light takes it to the $^4T_1$ level.. B : The energy levels and transitions. C : The resulting absorption spectrum and fluorescence of ruby. Note the broad absorptions and the resulting broad transmissions giving ruby its red colour with a slight purple overtone. (Nassau, 1983).

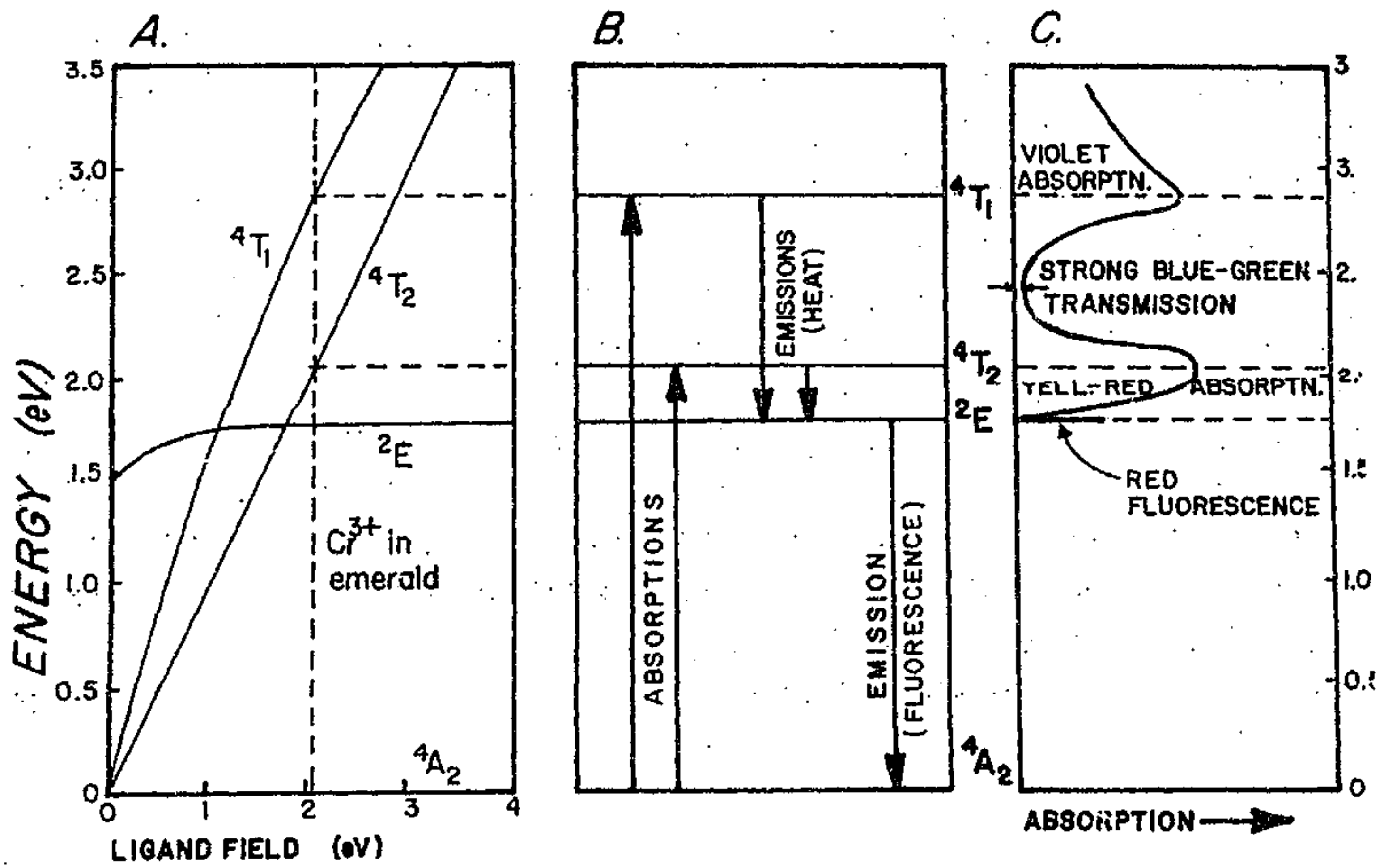


Figure 11 :The absorptions and emissions of chromium (Cr^{3+}) in emerald ($BE_3AL_2Si_6O_{18}$). A :Because the ligand electrical is slightly reduced, then when white light is shone on emerald, photon energy at $^4T_2$ is absorbed at 2.05 eV rather than the 2.23 eV of ruby. The $^4T_1$ level is lowered from 3.0 eV to 2.8 eV. B : The energy levels and transmissions. C : The lowering of the $^4T_2$ level results in the green-yellow absorption in ruby changing to a yellow-red absorption. The red transmission disappears and the blue transmission increases leading to the emerald's green colour. Note the very low absorption indicated by the small arrows. (from Nassau, 1983).

physical world. G. F. Stout has claimed that they are not part of " the executive order of the material world " (Stout, 1904, p 153).

However, it does seem that photon energy and its interaction with electrons gives a physical role to colour. The old adage is that atoms are not coloured and therefore colour has no role at the cutting edge of microphysics. Yet if photons are always interacting with electrons (Nassau, 1983), then they are having a role at the quantum level of physics in their changes of energy levels of electrons acting in producing colour. If we make the leap and identify colour with photon energy / wavelength, then we might have a very strong physicalist theory. As Nassau (1980) says:

> Colors come about through the interaction of light waves with electrons. Such interactions have been a central preoccupation of physics in the 20th century.... indeed, color is a visible (and even conspicuous) manifestation of some of the subtle effects that determine the structure of matter " (p. 106).

Let us briefly consider the mechanisms for the colour of metals and semiconductors (Nassau, 1983). (Figure 12). In metals, electrons are very free to move thus explaining their excellent electrical and thermal conductivities. The free electron gas model has been replaced by a full quantum mechanical band model with the electrons still free to move. Because of this freedom when light falls on a metal, it is so intensely absorbed that it can penetrate to a depth of a few hundred atoms, typically less than a single wavelength (Nassau, 1983, p. 164). Since metal is a conductor of electricity, this absorbed light, which is, after all, an electromagnetic wave, will induce alternating electric currents on the metal surface (Nassau, 1983, p. 164). These currents immediately remit the light out of the metal providing the strong reflection. Nassau (1983) says there is a paradox here in that " It is exactly because of this extremely strong absorption of metals that absorption does not have an opportunity to occur! " (p. 164), thus leading to the typical metalic appearance. It is interesting to look at some coloured metals, such as copper and gold (Figure 13). From Figure13, we can deduce that copper and gold unlike other metals do not absorb as completely at the high energy end of

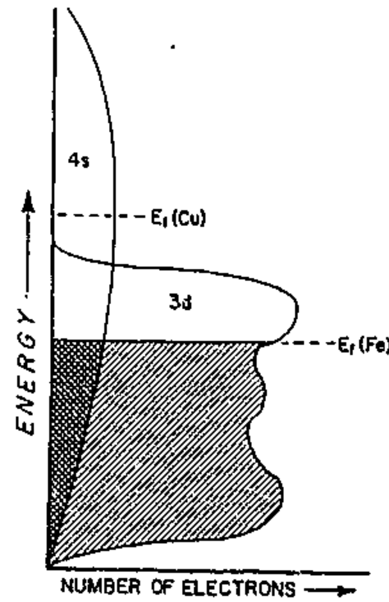


Figure 8-9. Density of states diagram for the metals iron Fe and copper Cu. From J. Slater, *Quantum Theory of Matter*, McGraw-Hill, 1951. Used with permission of McGraw-Hill Book Co.

Figure 12: The energy bands of copper (Cu) and iron (Fe). The band structure of Cu is $3d^{10}4s^{1}$ providing 11 electrons instead of 8 in the $3d^{6}4s^{2}$ structure of Fe. The 3d band of Figure8-9 is accordingly filled completely, and the 4s band is half filled to the level marked Cu. Since the density of states above this level becomes smaller as the energy increases, not as many transitions can occur at higher energies in the blue than at lower energies in the red part of the spectrum. Hence, these quantum interactions produce the reddish colour of Cu as more blue is absorbed. (from Nassau,1983).

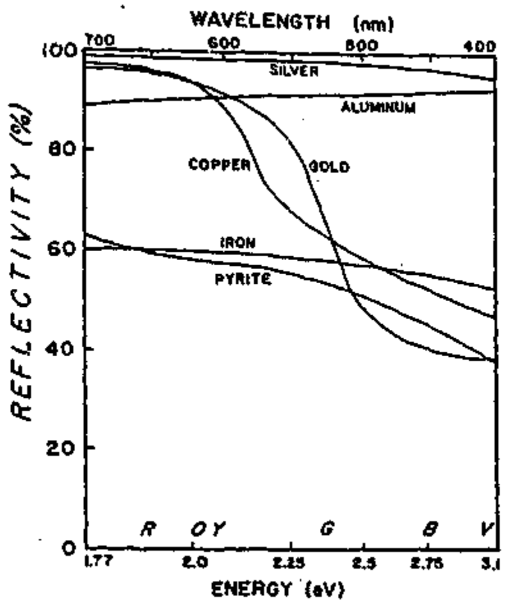


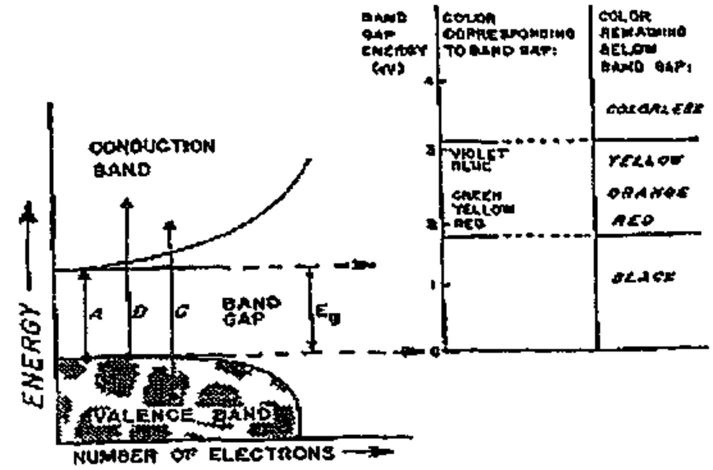
Figure 13: The reflectivity of a number of metals, including the metallike " fool's gold" pyrite feS_2. The colours depend on the interactions with electrons in the band structure. (from Nassau,1983).

the spectrum and hence do not reflect as well, thus leading to their reddish and yellow colours. The band structure of orbitals of copper is $3d^{10}4s^{1}$ which provides 11 electrons compared with 8 in iron which has a similar structure. This means that the 3d band for copper if filled completely and the 4s band is half filled. The result is that the density of states above this level for copper is smaller than that of iron. Thus not as many transmissions can occur at the higher energy levels in the blue compared with the lower energy levels in the red part of the spectrum. Hence the colour of copper. Both the 3d and 4s bands constitute the conduction band for metals. Thus any excitation from the absorption of photons can proceed to the higher levels and to conduction. Thus these quantum effects at these microphysical levels determine the colour, and are effects at the "executive" level of nature.

In the case of semiconductors, they have a band-gap between the valence band and the conduction band, the size of which determines the colour (Figure 14). A substance with a large band-gap is diamond. It has a band-gap of 5.4 eV and thus no light in the visible spectrum can be absorbed and pure diamonds are colourless. When there are impurities, such as nitrogen and boron, then diamonds can be coloured as they help bridge the band-gap (Figure 15). So once again, quantum effects with electrons determine the colour of objects. In Figure 16, the absorption spectra of various coloured diamonds are shown, which are produced by the impurities nitrogen (N) and boron (B). With both metals and semiconductors we have either broad absorptions or little absorption leading to broad reflectance spectra.

In this chapter, I have laid great stress on the quantum processes that underly colour mechanisms of objects in the natural world. I have emphasized the role of electrons in this process and the other quantum mechanisms (vibrational and rotational transitions) pointed out by Maloney (1986). All of these mechanisms interact with the effects of the incoming photons. These processes lead to the broad absorption bands observed in all organic compounds (Kauzmann,1967) and in non-organic objects (Maloney,1986). These broad tunings of absorption lead to broad bands of reflectance as Maloney (1986) has emphasized that the half width of a typical absorption band is approximately one half of the visible spectrum.

Figure 14: The absorptipon of light in a semiconductor, i.e. a band-gap material. The variation in colour with the size of the band-gap (E_g) shown on the right. Diamond with a band-gap of 5.4 eV can absorb no light in the visible spectrum and is therefore colourless (from Nassau,1983).



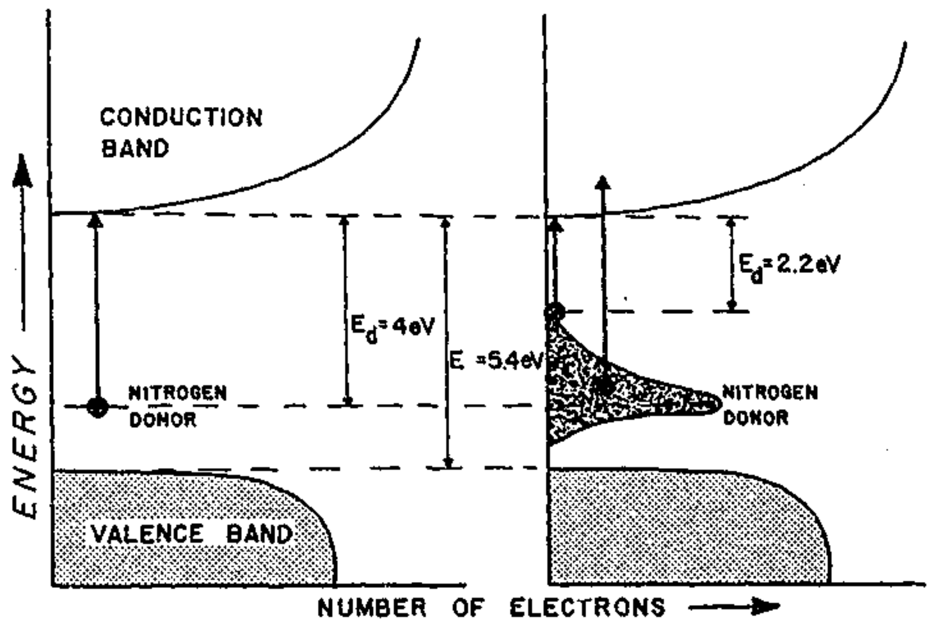


Figure 15:Diamond has an energy gap of 5.4 eV and is colourless. If a small amount of nitrogen impurity (1 in 100.000) is added,with the nitrogen merely replacing carbon atoms in the diamond structure, then a yellow colour is produced. The nitrogen donor reduces the gap to 2.2 eV by processes such as thermal vibrations leading to broadening of the nitrogen donor into a band. A much rarer green colour can result from a nitrogen content of 1 in a 1,000. (from Nassau, 1983)

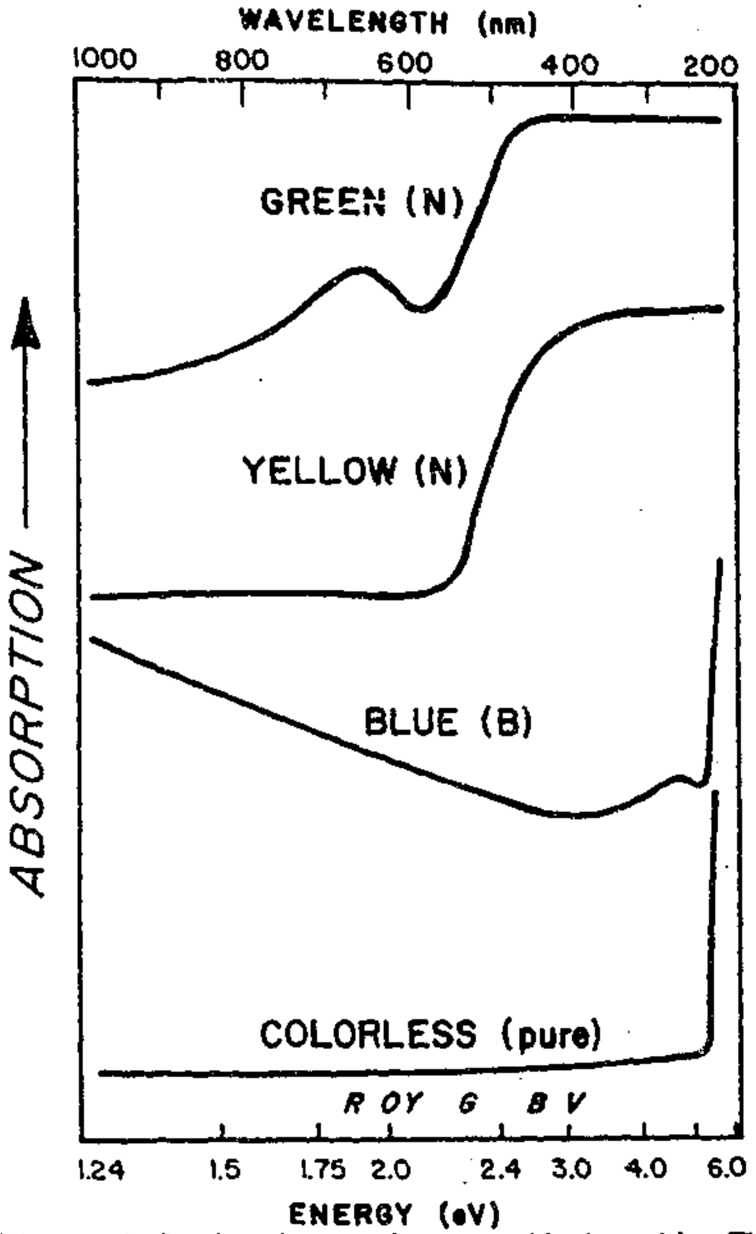


Figure 16: Semiconductor colour caused by impurities. The absorption spectra of diamond produced by nitrogen (N) and boron (B) impurities. At a level of one or a few boron atoms for a million carbon atoms, the above resulting absorption spectrum produces an attractive blue colour. Natural diamonds of this colour are rare and highly prized (e.g. the *Hope* diamond). These colours show the vital role of quantum effects at the electron level. (from Nassau, 1983).

These mechanisms appear to underly why there are so few metamers in the natural world, which suggests a direct realist account of colour, so there is no need to consider disjunctive processes for colour vision.

CHAPTER 9.0

9.1 A Brief Conclusion for PE / W Theory.

Up to this stage in this thesis, I have tried to show that some of the major objections to realism about colour and to wavelength realism in particular, no longer have such dramatic force. I have examined a number of colour processes which have been claimed to refute realism about colour. I argue that they don't have this role so obviously. This has particular force if metamers don't occur under natural conditions, which removes the need for disjunctive theories of colour. I now wish to revive photon energy / wavelength theory without any disjunctive overtones, as it is based on the fact that natural objects have very broad spectra of emitted and reflected light. This is unlike metamers which have a number of peaks in their spectra. I do concede, however, that wavelength theory needs to be expanded to include the responses of the perceivers to account for such context effects, such as the simultaneous contrast effects, coloured shadows and filling-in mechanisms. But I feel that some of these context effects can be accounted for in terms of topic neutrality, rather than entirely by an neo-Lockean account. However, my theory is still a version of Jackson's (1996) and still contains a neo-Lockean component or an anthropocentric component for these context effects, but the physical end of the causal process is photon energy / wavelength, rather than Land's reflective lightness triples. However, unlike Jackson, I view colours in the natural world as properties that objects possess across observers, conditions, and times (Watkins, 1997). I also feel that my position helps to rule out subjectivism about colour as all subjectivisms rely in some way on the objections based on the colour processes we have discussed. However, Campbell (1993), as I mentiuoned earlier, has reluctantly suggested that we might need to have a full-scale error theory of colour. He says that:

> according to this view, the experience of the world as coloured involves a double mistake. In the first place, no colour is a physical property of the environment; contrary to how things seem.......in the second place, no sense data.....are coloured either. Human perceivers have complex neural states that are projected as colours.... there are no colours. Here we have a desperation option indeed (p. 266-267).

This is an eliminative view of colour, e. g. nothing is coloured.

It is important to examine the concept of projection, which Campbell (1993) says is used freely by subjectivists of all persuasions (Boghossian and Velleman,1989; Hardin,1988; Shoemaker, 1990; McGilvray,1994). Armstrong (1993) points out some of the problems for the concept. He says:

> I believe, however, that projection poses more difficulty than its supporters realize. .... Contrast the colour of surfaces. The alleged projection is exceedingly precise..... the boundary of a colour change occurs just here. At this point it is worth remembering that 'projection' is but a metaphor. What is happening according to a projection theorist is that we mistakenly take the physical surface to be coloured. But if each of our brains picks out just the same precise surface area to make a mistake about, then must not something about the area itself be cuing us off? And then why can't this something be the colour of the surface? (p. 272).

I propose that this something is the broad wavelengths produced by photon energy interacting with objects. I feel that wavelength theory relieves us of this desperate subjectivism option about colour. In fact, one positive feature of a wavelength explanation is that it allows a consistent account of the 15 causes of colour proposed by Nassau (1983) that neither reflectance or disjunctive realism can accommodate. Despite the various physical mechanisms underlying colour, they all produce different and significant broad wavelengths as the one consistent physical factor in colour generation. It is difficult to imagine how subjectivism would provide projection mechanisms to cover these different physical mechanisms. While I am opposed to the subjectivism described by Campbell, overall, I like Campbell's (1993) conclusion, about the relationship between subjectivism and Armstrong's Australian realism, in that he says that subjectivism in the form of a full-scale error theory views the experience of the world as coloured involves a double mistake. He says:

> In the first place, no colour is physical property of the environment; contrary to how things seem, objects in the outer world would not be coloured were there no perceivers with colour vision. (objectivism is false.) In the second place, no sense data-or visual field patches understood as psychological states of perceivers—are coloured either. (subjectivism in the Lockean tradition is false). Human perceivers have complex neural states that are projected as colours.
>
> Projection is the first error. Experiencing what is projected as yellow, or turquoise, or whatever, is the second. There are no colours. Here we have a desperation option indeed. Armstrong's philosophy of colour, like many a position in philosophy, draws a good deal of its appeal from the manifest difficulties in each of its rivals (p. 267) [9].

Campbell can't see a way out of the impasse in that he sees that " dualism and reductionism seem equally unacceptable (p. 266). To attempt to overcome this impasse, I will now examine a range of views that are against a primary quality account such as my PE / W theory. They vary from objective accounts to either subjective or eliminative accounts (see Table 3), but most of their arguments depend on the colour phenomena I have analysed. As this table shows, there is an extraordinary range of theories about colour vision, all of which rely on these colour concept.

CHAPTER 10.0

10.1 Introduction

Up to now, I have put forward my theory of colour being based on the PE/W mechanism. This theory depends in part on showing that a number of visual phenomena do not give strong support for subjective theories of colour, such as the theory proposed by Hardin (1988). I now propose to examine other theories of colour, both objective and subjective. In doing so, I will relate my objections to these visual phenomena to these theories and attempt to show their arguments depend on them

. I will now look at other objective theories of colour. To facilitate this section of the thesis, I have prepared a Table 3, which I adapted and expanded from a Table devised by Armstrong (1968b) to classify theories of secondary qualities. In Table 3, the three horizontal rows I took directly from Armstrong and they give the nature of colour qualities. The Dualist row says that colour is the non-physical property of non-physical entities. The second row is called Attribute in which colour is a non-physical property of physical entities. Attribute is an interesting concept as Armstrong conceives it. He would describe colour or any secondary quality as an attribute because:

> The colour of the surface is an intrinsic, irreducible and observer-independent property of the surface, but it is also an additional property over and above the properties that professionally concern the physicist (p. 232).

The third row is Materialist where colour is a physical property of physical entities. Armstrong (1968b) had three columns: Subjectivist, Lockean, and Realist. I have added two more: Relational and Elimination. These columns are meant to show the location of colour.

Thus a Subjectivist / Dualist, such as Hume or Descartes would classify colour as a non-physical property in a non-physical mind. A Subjective / Attributist would hold according to Armstrong a conjunction of views that colours

TABLE 3 COLOUR AS A SECONDARY OR A PRIMARY QUALITY

			SUBJECTIVIST	LOCKEAN	REALIST	RELATIONAL	ELIMINATION	REPRESENTATION
			WHERE LOCATED					
			MIND OR BODY PROCESS	**POWER IN EXTERNAL THING TO CAUSE A MIND OR BODY PROCESS**	**EXTERNAL THING**	**RELATION OF EXTERNAL THING & MIND OR BODY PROCESS**	**MIND OR BODY PROCESS**	**IN BODY PROCESS**
DUALIST	**NATURE**	**Non-physical property of non-physical entities**	Hume Descartes	Locke			K. Campbell (1988) F. Jackson (1982) B. Maund C. Landesman	
ATTRIBUTE		**Non-physical property of physical entities**	Russell	C.B. Martin	S. Alexander J. Anderson D.M. Armstrong (1961)			
MATERIALIST		**Physical property of physical entities**	Boghessian & Velleman Zeki Gouras Livingstone Valberg Zrenner Abranov Akita C. L. Hardin	J.J.C. Smart(1961) M. Smith R. Shepard M. Johnston (1992)	D.M. Armstrong (1968) J.J.C. Smart(1975) D. Hilbert J. Westphal? D. Lewis F.Jackson(1996) W. Webster (2001) Tye (2000) Matthen (1999)	E. Thompson E. Averill J. McGilvray		Tye (1995) Harman (1990) Lycan (1996)

are sense data that are not in the mind and cannot be identified with physical objects or the surfaces of physical objects. Armstrong could only find Russell to hold this view for a while. I have not found another candidate. A Subjectivist/ Materialist would hold the view that colours are properties located in the brain. A large group of physiologists and philosophers are in this category.

The Lockean column raises some nice issues. Armstrong classifies Locke as a Lockean / Subjectivist who is someone who believes that:

> It is the surface of the physical object that is blue, but what constitutes its blueness is the object's power to bring about sensations, sense impressions or sense data having a certain unique quality..... in or before the mind of a normal perceiver, in standard conditions (Armstrong.1968b, p. 226).

Armstrong argues that this involves a non-physical property of a non-physical entity. For the Lockean / Attribute classification Armstrong cites some unpublished views of C. B. Martin and I can find no other candidate. The Lockean / Materialist classification describes a dispositionalist who argues that colour is a power in an external thing to cause colour in a physical mind or body process. A number of philosophers hold this view.

The realist column has no one under dualism, but has three entries under Attribute, including an early view of Armstrong (1961). As would be expected the Materialist / Realist cell has a large number of entries. In the relational column, only the Materialist / Relational has some entries. In the Elimination column, Campbell (1988) and Jackson (1982) appear under Dualist / Elimination for their arguments for an epiphenomenal account of colour and for Jackson's (1977) views about sense data. I have also put Maund and Landesman in this cell as they have views that there is no such thing as colour, there is only an illusion in the brain.

Table 3 is not meant to give an exhaustive theoretical account of colour, but it will help me relate the various theories I propose to examine in the following chapters.

10.2.1 Some Other Approaches to Realism about Colour

I will commence in the next two sections by examining some other theories in the Materialist / Realist cell of Table 3, which also argue that colour is physical property located on an external thing.

10.2.2 Akins and Hahn on Objective Colour.

Kathleen Akins & Martin Hahn (A&H) (2000), who support a form of objectivism, have written against some other objective accounts of colour in an important paper called " The Peculiarity of Color". In this paper, they critically examine the objective views about colour held by Frank Jackson, David Hilbert and Evan Thompson. I have classified A&H with a question mark in Table 3 as their form of objectivity about colours is rather unusual.

10.2.3 Jackson's Primary Quality View of Colour

Akins & Hahn (A&H) correctly point out that Jackson has a prime intuition about colour—namely:

> 'Red' denotes the property of an object putatively presented in visual experience when an object looks red (Jackson, 1996, p. 200). (Principle 1)

Jackson argues strongly that:

> we examine objects to determine their colour: we do not introspect. We look out, not in (p 200).

A & H also point out that Jackson has another a priori principle for perceptual presentation. This is the essential role for causation. A & H quote Jackson as:

> the property of objects putatively presented to subjects when the objects look red is at least the normal cause ot their looking red (A &H, 2000, p. 217.) (Principle 2).

A & H then argue that given these two principles that the question of the objectivity of colour for Jackson is reduced to the question of determining the normal causes of colour experiences. And if there are such normal causes, then colours are objective, if not then they are not objective. A & H then argue that these two principles by themselves leave room for, and indeed suggest, a Lockean possibility that colours are the powers of objects to produce certain sensations in us rather than being sets of primary qualities. As they correctly state, Jackson mounts what I regard as a strong argument (Prior et al., 1982) that dispositions cannot be causes. Instead, it is their categorical properties that have this role. So Jackson argues that colours are the catergorical properties of colour dispositions, not the dispositions themselves. In an earlier paper (Jackson & Pargetter, 1987), he put it quite clearly that:

> This paper is a defence of exactly what Locke most wanted to deny. It is a defence of the view that colours are non-dispositional properties of objects as 'primary' in their nature as shape and motion. (p. 127).

They point out that fragility is not a cause, but its categorical basis is and stress that we can't see fragility. In a concise line, they say that " We perceive colour, but infer fragility" (Jackson & Pargetter, 1987, p. 131). There is considerable dispute in the literature about dispositions and their categorical bases (Crane, 1996; Martin, 1994; Martin and Heil,1998; Bigelow and Pargetter,1999; Molnar,1999). However, I consider that Jackson and Pargetter's (1987) concept works well for colour as we see colour and only infer dispositions. Thus the categorical argument might not work for all dispositions, but it appears to do so for colour. (see my discussion of this issue in Chapter 2.2).

A & H criticize Jackson's approach by arguing that colour perception is distinctly " peculiar" in that there is a great deal of variability between our colour experiences and what they are experiences of, i.e. what causes them. Thus they say that:

> an object which appears red to me now would not appear red if the illumination were different, or if I were closer or farther from it, or if the human visual system were different or if I were colour blind, and so forth. Moreover, this kind of variability is generally regarded as the very

> hallmark of subjectivity.......if colour is to be an objective property, then, variability needs to be tamed. (A & H, 2000, p. 218).

A & H say that philosophers who subscribe to some version of Jackson's Principle 1 usually cope with this variabilty problem by an appeal to standard conditions, i.e. red objects are all objectively red because they all appear red to normal viewers under standard conditions. They then say:

> Interestingly, Jackson does not take this "standard conditions" route. Nor, as a matter of fact, is it open to him to do so (A & H, 2000, p. 218-219).

It is not open to Jackson according to A & H, because the appeal to standard conditions is a counterfactual property and hence a dispositional one.

This is simply an incorrect version of what Jackson says. Contrary to A & H, he embraces standard conditions etc. when talking about variation, he says:

> Accordingly, from now on I will be concerned principally with colour in a thoroughly anthropocentric sense tied to normal humans in normal circumstances. Thus, we can mostly work in terms of the following clause:
>
> O is red at t iff there is a property P at O that typically interacts with normal perceivers in normal circumstances to make something that has it look red in the right way for that experience to count as a presentation of P in that object (Jackson, 1996, p. 206).

A & H then argue that Jackson, instead of taking the standard conditions route accepts the consequences of his arguments and denies that objects are coloured tout_court. They discuss an example raised by Jackson. He pointed out that a page of printing could be composed of yellow and magneta dots yet look red from a normal reading distance. Jackson accepts that his theory would say that the same object has different colours at different distances.

This circumstance raises some important issues for a primary quality or physicalist account of colour. Jackson realizes this when he says:

> the primary quality account should regard attributions of color as relativised to a kind of creature and a circumstance of viewing. The primary

quality account is the result of combining a causal theory of color.......the view that the colors are the properties that stand in the right causal connections to our color experiences......with empirical information about what causes color experiences: and a causal theory of color takes as fundamental color for a kind of creature in a circumstance (Jackson, 1996, p. 204).

It seems to me that Jackson's view can be explained from the point of view of wavelength theory. It would seem that the wavelengths coming from the papers are both yellow and magneta but the perception of red is produced by the additive wavelength integration of the two colours. A & H argue that the converse variability is also a problem for Jackson's view, that is, the same colour appearances are often caused by multiple diverse causes. In other words one and the same colour appearance can be caused by different kinds of surface properties. The obvious candidate for this are metamers, but A & H refer instead to the work of Nassau (1983) cited earlier. They say that Jackson does not consider the fact that Nassau shows that there are a diversity of physical mechanisms for a single colour experience. Hence, Jackson can't claim that there is a single property—'redness'—that is common to all objects that appear red.

However, as we claimed earlier (Chapter 8), there is a common mechanism behind all of Nassau's mechanisms. It is the same broad spectral wavelengths generated by the diverse mechanisms. A & H point out that this has forced Jackson to accept a disjunctive account of colour (Jackson, 1996, p. 215). Jackson (1996) accepts that excessively disjunctive properties cannot be causes, so he proposes a rather weak contention that:

> Even if most red things do not belong to a kind responsible for them normally looking red, there will turn out to be, all the same, sufficient similarity between what typically makes things look red to us to be able to identify red with a disjunctive property that is sufficiently unified to count as a cause. For it is hard to believe that there is not enough rhyme or reason to things looking red given the evolutionary importance of colour vision "(p. 214).

A & H conclude that:

> In the end, then for Jackson the objectivity of colour stands and falls on his conjectur e that some distal property does unify all things that look red, a property colour vision evolved to detect. If no such property exists, we would have to declare colour a pervasive illusion (A & H, 2000, p. 221).

Jackson (1996) proposes a solution in that:

> The issue then in the case of color is whether there is a unifying distal property. Now there is some reason to hold that triples of integrated reflectances correlate closely with perceived color. The fine detail is not important here, and needless to say, it is controversial. But roughly a triple of integrated reflectances is the result of taking the reflectance—that is, certain proportions of reflected to incident light—over three bandwidths, scaling, and then summing. The result correlates closely with apparent color of reflecting surfaces. (p. 215).

Jackson concludes that:

> We causalists must think of the value of the triple for a given color, red, say, as what unifies the possibly highly disjunctive basis that is responsible for the disposition to look red in normal circumstances. It is what prevents the basis counting as excessively disjunctive. (p. 215).

However, there is no evidence that Land's triples are any more successful in accounting for the disjunctive nature of metamers than other approaches. Instead, if one accepts our earlier arguments about the lack of metamers in the world, then PE / W theory can give a non-disjunctive account of colour. Metamers, based on our artificial pigments and electronic devices, simply trick our cones in a way that does not occur in life and in the development of colour vision. I would argue that if Jackson's theory has the integrated triples replaced by my PE/W process, then it provides an excellent account of colour by having colour in the world being based on a broad spectrum of reflected light.

10.2.4 Hilbert's Anthropocentric Theory.

Hilbert's (1987) views on colour have been addressed briefly in Chapter 2, but A&H's criticisms will now be considered. Hilbert argues that the distal component for colour is the surface spectral reflectance of an object. This is the ratios of the flux of the incident light to the flux of the reflected measured for each wavelength. The intensity and wavelength of light reaching any given point is given by the spectral power distribution of the light, which describes the energy per second at each wavelength. Hilbert says that these two measures are the main options for a possible correlate of colour. The power distibution is a wavelength concept of colour, and Hilbert argues that the other measure is independent of wavelength. This raises the question of how Hilbert justifies this role of surface spectral reflectance? He does it by appeal to Land's work with Mondrians. As mentioned earlier, Land adjusted the light shining on two papers of different colour, so that they both reflected the same amounts of light in each waveband. Hilbert concludes that:

> It is clear that this experiment decisively establishes the independence of perceived color from the spectral power distribution of the light reflected from a coloured surface. Two surfaces reflecting light with the same spectral power distribution can have a different perceived color. At the same time, it shows that in the circumstances of Land's experiment, perceived color is independent of illumination. ...... The fact that perceived color is not variable in the way that transitory colors are casts doubt on the wavelength conception of light...this conception of light entailed that perceived color should be largely dependent on illumination. (p. 64).

The work of Young (1987) mentioned above shows that this cannot be concluded from Land's experiments. Instead, a wavelength conception is supported in that wavelength information is still present in these experiments, even with the narrowest of filters.

A & H's main criticism of Hilbert is in relation to metamers. With metamers it is obvious that different surface spectral reflectances have the same colour.

Hilbert attempts to cope with this problem by what he calls a form of anthropocentric realism. For Hilbert, colour is an objective property of the world (i.e. surface spectral reflectance), but human observers, given the limitations of the human colour system, are not able to discriminate (under normal viewing conditions) between all of the actual colours. Hence metamers are misperceptions. Hilbert argues that this concept of misperception is supported by the fact that most metamers can be distinguished under some form of illumination, i.e. the true difference in reflectance can be detected under this illumination condition (Hilbert, 1987, p. 131). This is a rather weak defence of his position. However, Hilbert makes an interesting comment on metamers, considering our position, that they don't appear in nature.

Hilbert (1987) refers to the work of Maloney & Wandell (1986), which he says has interesting consequences for the understanding of metamers. The existence of metamers implies that because the human visual system has only 3 kinds of receptors, then these are not enough to accurately determine all the parameters necessary to detect all naturally occurring reflectances. Maloney and Wandell showed that with 3 kinds of receptors there could only be 2 parameters in a model of reflectance. They then went on to show that more parameters are needed before human beings could detect metamers accurately. They suggested that as few as 3 to 6 parameters would suffice to account for most of the variation in surface spectral reflectance. Hilbert (1987) concludes that:

> the small number of parameters required to account for existing variations in reflectance implies that metamerism may not be common. The visual system is not faced with the problem of determining a property that can vary in an unconstrained manner (because of the small number of parameters required). Although there are possible differences in color that are undetectable in normal circumstances, the actual occurrence of such differences appears to be relatively rare. In general, objects that look to have the same color will have the same color. (p. 130-131).

This is very interesting support from quite a different direction for our claim that metamers don't appear frequently in the real world.

My conclusion about Hilbert's theory is that it does not handle well either metamers or luminous colours which don't have reflectance profiles. The PE / W mechanism would appear to give a better account.

Thompson's View 10.2.5 on Colour.

Thompson (1995) is a rather odd theorist to be counted as an objectivist about colour. [3] Indeed, Akins & Hahn (1999) do point out that while Thompson is not only not an objectivist, he is also not a subjectivist about colour. In fact, he fits into the Materialist / Relational cell of Table 3. However, A&H's analysis of the position of Thompson and his colleague is not very accurate or detailed. I will attempt here to do just that. Thompson (1995) and Thompson, Palacios & Varela (1992) reject both an objective and a subjective account of colour. Instead they propose what they call an enactive theory of colour. They say that:

> the enactive view of perceptual content is also different from both the 'externalist' view that perceptual content is provided by distal properties and the 'internalist' view that perceptual content is provided by perceptual qualities (qualia). According to the enactive view, the contents of perceptual states are to be type-identified by the way of the ecological properties perceived, and these ecological properties are to be type identified by way of the states that perceive them (Thompson et al., 1992, p. 23).

They accept that there is circularity in this enactive view, but they claim it is informative, because colour vision and the ecological properties detected by colour vision have in the course of evolution selected for each other. Thus the enactive view of perceptual content follows from animal-environment codetermination. They then argue that colour is both ecological and experiential. This is a difficult theory to comprehend as it implies that colour is a relation if it is neither objective nor subjective. They say this clearly when replying to Hardin (1992):

> In Hardin's view, colors are such intradermal entities (chromatic neural states); in our view they are relational properties of perceiving animals and their environment. (Thompson et al., 1992, p. 66).

They specifically deny that their concept of colour as a relational property was similar to Locke's (1690/1975) concept of colour as a relation. They argue that Locke held that colour is relational because it is a " secondary quality", a disposition of objects to cause sensations in a perceiver. They argue that according to the Lockean view, colour is not merely a relation, but is also dispositional and subjective. They claim that their enactive view does not rest on a distinction between secondary and primary qualities, in that:

> our argument that not only color but also other high-level, spatial properties of the scene (object surfaces as determined by shapes and boundaries) are relational runs directly counter to the Lockean and Newtonian attempt to draw a principled distinction between color as a secondary quality, and size, shape, and so forth, as primary qualities. Rather, we have emphasized the relational nature of the perceptual environment as a whole resulting from the enactive dimensions of visually guided activity (Thompson et al., 1992, p. 23-24).

Let us now look at the criticisms of Thompson et al., (1992) of the objective and subjective approaches to colour. They call the objective view " computational objectivism", which sets out to determine whether some sufficient subset of the properties of colour can be identified with such physical properties, such as surface spectral reflectance. They base their arguments on the criticisms of Hardin (1998), which assert that colour has opponent colours and unique and binary colours. None of these categories can be indentified with physical properties, therefore, "color cannot be reductively identified with such organism-independent, external properties" (Thompson et al., 1992). That is, given only light wavelengths or spectral reflectance profiles for surfaces, we cannot state generalizations about hue. They do not stand in relations to hue that can be described as unique or binary; opponent or non-opponent; saturated or desaturated. They conclude that:

> there is simply no mapping from such physical properties to the properties of color that is sufficient to establish the objectivist identification (Thompson et al., 1992, p. 16).

Of course, we have already seen that Hardin's arguments based on opponent processing are not as strong as first thought.

They go on to assert that Hardin's criticisms can be made stronger if hue is considered across dichromatic, trichromatic, tetrachromatic and pentachromatic colour spaces. They argue that dichromatic spaces would have no binary hues as they have only one opponent-hue pair and tetrachromatic colour hyperspace would contain ternary hues not found in trichromatic space. Thus they conclude that these different kinds of hue do not map onto properties of surface spectral reflectance. These assertions have been strongly criticized by Jacobs (1995,

For example, Jacobs (1995) says:

> It is argued that the 'first concern' of the enactive view (Thompson et al., 1995) of color vision is to determine more precisely the dimensionality of color vision of different animals because variations in dimensionality hold cues as to the color world of an animal. But in doing so the authors show an eager readiness to accept all kinds of indicators that can be far less than compelling [my emphasis] (p. 40).

Jacobs (1995) points out that Thompson et al., (1995) lay great stress on the argument that the shape of the wavelength discrimination function can be taken to indicate the type of colour vision system... a trichromatic systems have two minima and tectrachromatic systems have three minima. Yet, Jacobs says that many wavelength discrimination functions reported for trichromatic humans show three minima. Thus what are the implications for arguments based on dimensonality ? Jacobs then says:

> To draw an example from comparative color vision, what are we to make of wavelength discrimination functions obtained for the pigeon, a putative tetrachromat? Some of the functions show three minima in the visible spectrum, others (Jacobs, 1981, p. 114) show only two. (p. 41).

Jacobs (1995) then says that:

> similar ambiguity surrounds the common practice of deriving color vision dimensionality from a count of spectrally distinct, first-stage filters......Various combinations of screening and cone pigments provide multiple filter possibilities in various avian (e.g. six in the pigeon-Bowmaker, 1977) and reptilian (e.g. five in a fresh water turtle-- Liebman, 1972) retinae. Whereas these provide the intriguing possibility of color vision dimensionality that greatly exceeds trichromacy, there is in most cases still a lack of consistently compelling evidence that the visual system of these animals fully exploit this first-stage potential....... in my view the moral is clear ..... although it may be pleasant and satisfying to draw fanciful diagrams of color space based on fragmentary evidence, one should not be deluded into believing that these necessarily provide insight into color experience. (p. 41).

Even supporters of muitiple dimensionality, such as Goldsmith (1990), urge some caution in interpretation. He says:

> The discussion of oil droplets and color spaces is largely theory. The color vision of birds is probably the most richly endowed of any vertebrates, but in no case do we have a total description of all pairs of pigments and droplets. Nor is it clear that the neural organization of the avian retina makes local regions more than trichromatic (p. 316).

It would seem prudent to reserve judgement on Thompson' claims.

In their criticisms of neurophysiological subjectivism, Thompson et al., (1992) concentrate on the work of Hardin (1998). While they use Hardin's criticisms of objectivism as important critiques, they don't conclude that Hardin's theory is adequate overall on this basis. Their position is not easy to grasp. While accepting Hardin' criticisms of the objective position, they argue that ecological considerations count against his position. They put forward three comparative arguments. First, they consider the polymorphism in the colour vision of the squirrel monkey and the spider monkey. In these species, all males are dichromats, whereas three-quarters of the females are trichromats. They propose a number of explanations of these features, but one appears the most likely. It is the hypothesis that the colours of fruits eaten by these species co-evolved with differences in colour vision (Snodderly, 1979). Second, they look at the colour vision of bees. They point out that the trichromatic vision of bees has been shifted towards the ultraviolet. Flowers attract pollinators by their food content, so need to be conspicuous from other flowers. On the other hand, bees need to recognize flowers from the distance. They conclude that: " this mutual advantage seems to have determined a co-evolution of plant features and sensory-neural capacities in the bee " (Thompson et al., 1992, p. 19).

Third, they point out that within the ecological framework of animal colouration related to species and sexual recognition has also been co-evolved. They go on to argue that these phenomena indicate that a purely neural explanation of colours (such as Hardin's) is incomplete.

These arguments do appear to be rather unusual. They do maintain what they call an interactive position in which colour is relationship. However, it does appear that there are two terms in the relationship which co-evolve. They are the external features of the plants, the insects and the animals and the sensory neural capacities of the perceiving organisms. So surely one can consider one term to be external and thus mind independent and in the world, and the other to be internal and mind and brain dependent. Even if both terms can modify each other, it would appear that each has physical properties that are independent of ecology. That is, an ecological explanation of a neural feature does not mean that the feature is not neural.

Their unusual approach to external features of colour is borne out by their comments on Averill's (1992) views. Averill argues that the proper question is not, are colours physical properties, but rather, what features of colour are physical properties? Averill claims that those features of colour that are physical are differences in reflectance, transmittance, polarization, and so on... in short the properties of physical optics. Averill then argues that the features that are perceptual are hue properties, that is, redness, greenness, blueness, and yellowness. Thompson et al., (1992) respond by saying :

> we like Averill's question, but we could answer it in a somewhat different way. Because we claim that colors are relational properties of animal-environment ecosystems, we are happy to say that colors have physical properties in Averill's sense as long as it is remembered that these do not exhaust the features of color and that they must be individuated in relation to the animal (p. 63).

It would seem that if they accept these physical properties, then it is hard to see how their relational concept can be applied to non-biological colour, which cannot be modified by ecological, evolutionary factors. Nassau (1983) illustrates many forms of non-biological colour which surely cannot be a relation in the way proposed by Thompson et al., (1992). These non-biological forms of colour have been set out in Chapter 8 and surely they have no ecological component.

10.2.6 The Principle of Objectivity (OP).

Akins and Hahn (2000) (A&H) mount a series of arguments against most forms of objectivism, but particularly Jackson's version. They argue that there are three criteria for the objectivity of colour which they say that all three philosophers agree to. A&H summarize these in their principle of objectivity (OP):

> Colour is an objective property if and only if whenever an object appears to have a certain colour, say, red, there is some distal property of that object which (i) normally causes it to appear red; (ii) is tracked by the appearance of redness; and (iii) is mind-independent (p. 232).

A&H argue that with the first criterion: (i) that there is a distal property causing something to appear red is held by most 'non-Australian' objectivists about colour, with Jackson adding the stipulation that dispositions can't be causes. Most other objectivists, including Hilbert and even Thompson dont agree with this. A&H argue that both Jackson and Hilbert endorse the tracking criterion (ii) in defending objectivism; and even Thompson endorses it in attempting to deny objectivism. They all agree that colour would not be an objective property of the world if:

there were a one-to-many relation between the distal causes and the colour experiences- that is, if one and the same distal property gave rise to a variety of colour experiences (A&H, 2000, p. 230).

A&H argue that Jackson and Hilbert expend considerable energy trying to defuse counterexamples, while Thompson tries to argue against objectivism with additional examples. A&H say that there are patently embarrassing facts about colour vision that weigh against (ii), such as what they call the peculiarity of colour. These are the limitations of colour constancy, the fact that a red shirt will appear many different colours depending upon the nature of the illumination, the distance to the subject, the effects of surround conditions. Jackson tries to counter these observations by relativising colours to subjects, circumstances and times, which gives content to the notion of normal. However, Hilbert tries to rely on colour constancy mechanisms as well as relying on the notion of the biological function of colour, i.e. what the colour system is trying to do, even if it is not able to that function under all conditions, in all viewers etc. In contrast, Thompson wants to emphasize these problems to discredit the objective view. I have tried to answer these objections (Chapter 7) in line with wavelength theory in conjunction with brain mechanisms.

In the case of the second criterion (ii) A&H stress that it is the existence of metamers that tend to disprove objectivity for Hilbert and the multiple material causes of colour for Jackson. They say that both Hilbert and Jackson must deny the seemingly disjunctive natures of the causes of colour. Hilbert tries to use the triple of integrated reflectances to deflect these problems. He argues that the existence of surface colour metamers indicates that human colour vision is limited and indeterminant with respect to objective, physical colour. That is, our colour perception sorts surface spectral reflectances into metameric equivalence classes that are anthropocentric because they are determined by the structure of the human visual system. Whereas, Jackson tries to distinguish between legitimate and 'excessively' disjunctive causes. Thompson, of course, wants to emphasize such multiple causes. However, A&H also point out that Thompson's own view of colour also utilizes a notion of tracking based on Gibson's notion of 'affordances'. Thompson argues that the purpose of colour vision is to integrate a physically heterogeneous collection of distal stimuli into a small set of perceptual equivalence classes. Of course, I want to say that metamers are not a real problem for colour vision given they don't occur in nature, so wavelength theory can be supported.

The third criterion (iii) is that the distal causal property must be mind-independent. A&H point out that all three theorists rule out dispositions of a certain kind, namely Lockean powers to cause a certain experience in a subject. They say that such powers are defined by their causal / phenomenal effects and hence they are not mind-independent. Instead, A&H say that one version or another of OP is held by virtually every contemporary philosopher who theorizes about colour. A&H say that they find OP deeply suspect not only due to criteria (i) and (ii), but for the relation between mind -independence and colour (criterion iii). They lay great emphasis on the relation between colour appearance and mind-independence. They point out that overall OP really defines a relation of co-variation between a distal, mind-independent cause and a colour appearance. They argue that in everyday talk, colours are attributed to objects. When we talk about colour 'appearances', we are often emphasizing the fallibility of our colour judgements, that is, how the objects in the world might actually be in spite of how we see them, in spite of how vision presents them as being.

A&H present an unusual argument against OP. They say that the problem with OP is that it is not satisfied by objective properties, such as size and shape. This is because things don't appear the correct size or the correct shape, we don't treat such cases as threatening the putative objectivity of those properties. There is no temptation to adopt a standard conditions account as in colour vision. They conclude that co-variation of phenomenal experiences with a mind-independent distal cause is not a necessary condition of objectivity. They also argue that OP does not provide sufficient conditions for objectivity. This is due to what A&H claim is a 'dodgy' method of meeting OP by defining a physical event that eventuates in the relevant sensation. As an example of this they point to Hilbert's use of the three triples of reflectance. These do not advert to any human experience, rather, they are mathematical descriptions of neurophysiological events that result in our colour sensations, and according to OP, count as descriptions of 'mind-independent' properties which are 'tracked' by those sensations. A&H argue that if OP makes colour objective, then it should admit of a seems / is distinction like size and shape, e.g. " if red objects are of "necessity" tracked by red sensations, in what sense is the " evidence" of colour sensations defeasible in principle? " (A&H, 2000, p. 237).

However, A&H don't allow for things like size and shape can be measured by other than vision, which makes it simple to have a seems / is distinction. This is why Jackson emphasizes his prime intuition view leading to relativity of viewer and conditions which don't apply to the other properties. A&H end up putting their own version of objectivity. They argue that colour can be considered objective if we grant the seems / is distinctions, such as their peculiarity concept of colour. This would mean jettisoning Jackson's prime intuition approach. They say that if one wishes to keep OP, then an objectivist must discount metamers, the effects of coloured surrounds, the apparent multiplicity of surface properties that cause a colour sensation, and so on. I think that I have gone some way to doing this, since I feel that our arguments about metamers and illusions allow objectivists to discount these items and to keep to OP. I have put a question mark against A&H in the materialist/ realist cell of Table 3, as I find that their seems / is distinction is difficult to maintain for colour compared with the shape of objects.

A&H distinguish three things about colour in their objective approach:

(1) the colours objects have

(2) colour appearances: experienced colours of objects

(3) the colours objects are judged (or believed) to have (colour judgements)

The concept of judgement is brought in by A&H in a section on new directions for colour analysis. They attempt to introduce a role for judgement in their appearance / reality distinction. They argue that if colour is objective then we must be able to draw a distinction between our representations of colour properties and colour properties themselves. They say that;

> the appearance / reality distinction must hold between, on the one hand the properties which objects are represented as having

> in our fully intentional perceptions of objects- in our visual judgments of object color.... and whatever color properties are actually exemplified. The distinction, if there is one must be between color attributes or *judgements* and colors, not between color *appearances* and colors, whether one takes color appearances to be phenomenal or not. This is what it would be to treat colors as objective in the ordinary sense (A&H, 2000, p. 239).

A&H go on to make a strong distinction between phenomenal appearances and colour judgements. They say:

> Yes, there is a phenomenology of color but, with all due respect to Hume, purely phenomenal states are very difficult- if not impossible- to get hold of and are unlikely to play a central role in ordinary vision. It might be best then, as many other philosophers have noted before us, that we not take up with, or posit such (unnecessary) unnatural beliefs (A&H, 2000, p.243).

This is obviously a strong rejection of a qualia approach to colour and is clearly related to the representationist approach to colour of Tye (1996a) and Armstong (1996a), that I will discuss later. It is interesting that A&H don't mention the large literature on this issue. I should mention that I support the belief / representation approach as compared with a qualia account of colour. But what is surprising is that A&H use this approach to attack Jackson's (1996) prime intuition account of colour.

Let us look at Jackson's (2000) more recent account of his theory he describes his prime intuition as being:

> " Red " denotes the property of an object putatively presented in visual experience when an object looks red (p. 154).

Jackson (2000) then goes on to spell out his primary quality theory against the standard dispositionalist theory. He argue that there is

(1) the prime intuition

(2) A conceptual truth about presentation: The property of objects putatively presented to subjects when those objects look red is (at least) the right kind of cause of their looking.

(3) Empirical discovery: The only plausible candidates to be the right kind of causes of objects looking red are certain complexes of physical properties of the objects.

(4) Conclusion; Therefore, redness is a certain complex of physical properties.

Jackson goes on to argue that while this theory rules out identifying red with the disposition to look red (and so on for all the colours), it does not rule out identifying colours with physically specified dispositions like the disposition to modify incident light into broad bands, in various ways, such as the mechanisms outlined by Nassau (1983). It is difficult to see why Jackson would not accept a judgmental account of colour rather than a qualia one, in keeping with his causal theory. However, Jackson would not accept an appearance / reality distinction for colour, as colour cannot be described by multiple methods in the way shape and other primary qualities can.

Overall, I would argue that we can encompass OP by my theory of PE/W. The first criterion of a distal property can be met by the broad wavelengths produced by the quantum mechanisms. The second criterion of tracking can be met by JND accounts of colour (see Chapter 15.0). The third criterion of mind independence is met by the distal property and the tracking arguments. I thus don't regard A&H's theory as a satisfactory objective account.

CHAPTER 11.0

11.1 Introduction

In this chapter I will look briefly at several other theorists (Table 3) who have taken a realist view of colour in a different form to that argued for in this thesis (Matthen, 1999; Campbell, 1993; Tye, 2000; Ross, 1999, 2000, 2001a,b). I shall try to show where they differ from my theory in that they also depend strongly on the colour phenomena I have been arguing against.

11.2: Pluralistic Realism about Colour

Matthen (1999) has argued for a new form of realism about colour, which he calls pluralistic realism. Matthen (1988) initially argued that colours are surface spectral reflectances (SSR's), but he gave up this position in Matthen (1992) and proposes a new theory of colour in Matthen (1999). Before analysing this new theory, I wil' look at Matthen's earlier views.

Matthen (1988) argued that chromatic perceptual states had the indication of SSR's as their biological function. For Matthen, the biological function of colour vision is to indicate SSR's. Matthen (1988) starts with an analysis of biological functions and perceptual content He lays great stress on the computational approach to perception and what he says is the striking feature of computational theories of perception. This is that they employ an intentional characterization of perceptual states. Matthen (1988) states that:

> Most other scientific treatment of perception concentrate on the external causes of perception and how they result in the stimulation of the sensory organs, the neurological organization of perceptual systems, and the discriminatory resources afforded to oganisms by perceptual systems.

Though not ignoring these important topics, the computationalists characteristically regard perceptual states as representing the external world and seek to explain them under this rubric ......Most philosophers today, and most computational theorists, are materialistically inclined: they are not inclined to allow that there could be a causally effective aspect of a perceptual state that is not material. For this reason, any widely acceptable foundational account of computational theories of perception must explicate what it means to endow a material state with representational content. It is my purpose in this article to develop a theory of perceptual content which meets this requirement (p. 5-6).

Matthen goes on to argue that computational theories tend to attribute distal content to perceptual states, i.e. they claim that we perceive things like rigid bodies, reflectances of surfaces and motion in three-dimensional space. Matthen says that this sort of theory avoids any internal state such as a sense-datum. Matthen proposes a theory of perceptual content based on biological functions. He proposes that computational models of colour vision provide a paradigm of this representationist approach to visual perception. He says that:

Computational theories are efforts to explain how perceptual states present external objects. The question I shall seek to address in what follows is this: What feature of a perceptual state makes it a presentation of a particular property, say redness? (Matthen, 1988, p. 7).

Matthen argues that it is surface spectral reflectance that is the feature. He bases this on the computational work of Land. Computational models of colour vision focus on the phenomena of colour constancy and try to show how indicators of surface spectral reflectance can be extracted from the retinal image. Matthen claims that the biological function of colour vision is to detect surface reflectance. Matthen then points out that the perceptual state with this function may fail to detect this feature. Matthen calls this "normal misperception", that is: the use of indicators that are imperfect, but nonetheless the best available. Matthen employs the notion of normal misperception to explain certain psychophysical and phenomenological features of human colour vision. For example, he addresses the problem of metamers that indicate that human colour vision is indeterminate with respect to surface spectral reflectance. Matthen holds that metameric matches of coloured surfaces are examples of normal misperception, because we do not correctly perceive the difference in reflectance, yet the misperception is not due to malfunction or maladaptation, but rather to the less-than-perfect nature of the indicators involved in colour perception. I don't think this an adequate answer to metamers. I think the proposal made in this thesis that metamers don't occur in nature is a better answer to metamers. Thus Matthen's theory has considerable problems.

Matthen (1999) has repudiated this theory and has put forward another one. He comments that he first changed his views in Matthen (1992) after reading Thompson et al., (1992) on their enactive theory of colour. Matthen (1999) starts by looking at what he calls narrow anthropocentrism by David Lewis (1997). Lewis (1997) drawing on folk psychophysics (FP) says that FP classifies colours as properties of the surfaces of opaque things and colour experiences are inner states of people. Lewis says that:

> when we take the theoretical terms to name the occupants of the theoretical roles, we arrive at ' definitions' such as these.
>
> D1: Red_is the surface property of things which typically cause experiences of red in people who have such things before their eyes.
>
> D2: Experience of red is the inner state of people which is the typical effect of having red things before the eyes. (p. 327).

Matthen argues that things like opponent processes and colour vision in other species makes narrow anthropocentrism and other forms of anthropocentrism with their emphasis on humans inadequate. He lays great emphasis on the colour system of pigeons following Thompson et al., (1995)'s emphasis on ecological factors. Matthen (1999) says that:

> the problem becomes acute when we consider color vision in other species. The pigeon has eyes with photoreceptors similar to our own, and retinal cells that treat the output of these receptors by "opponent processing".

However, the pigeon has four visual pigments. (we are trichromats, pigeons tetrachromats.) The pigeons 's fourth pigment is sensitive to ultraviolet, and is thus capable of seeing reflectances in the ultraviolet range of the spectrum. Further, it computes three difference values....it samples three wavebands, not just two. Consequently, pigeon colors have three hue-components; the colors they experience are not completely describable, as ours are, in terms of two such components (p. 51).

Matthen (1999) argues that Lewis's brand of anthropocentrism--lies behind his own defence of realism. Lewis (1997) says:

> An adequate theory of colour must be.....commensensical. [This] can be compromised to some degree....But compromise has its limits. It won't do to say that colours don't exist....[It] it is a Mooream fact that the folk psychophysics of colour is close to true. (p 325)

Matthen (1999), however, argues that:

> The trouble is that the " folk psychophysics of colour " is not just different from pigeon color psychophysics, but incompatible with it. Folk psychophysics does not just tell us that every reflecting surface is experienced as reddish or greenish or bluish or yellowish; it insists that every chromatic surface is so.......If these propositions are true to true, what of pigeon psychophysics? It proclaims the existence of hues unknown to humans, and asserts that ultraviolet is a color. It makes hue comparisons in a dimension orthogonal to red-green and blue-yellow and denies that every color is reddish or greenish or bluish or yellowish. Pigeon psychophysics must, then, be (close to) false. And such psychophysical differences are endemic right across the animal kingdom........If different organisms experience colors differently, whose experiences are we going to use when we construct " relations among colours in the image of relations among colour experiences? " (p. 71).

There are some issues I would like to raise about these claims. First, the claim about tetrachromatic vision in pigeons is not without dispute, as I showed above in discussing Thompson. Matthen (1999) bases his arguments on the claims of

Thompson et al., (1995). I feel that the evidence of Jacobs (1995), (Chapter 10.2.5), makes it difficult to support these strong assertions.

I am not claiming here that tetrachromacy is impossible, but I want to draw attention to the ambiguity of the evidence. I think Matthen could perhaps make more mileage by emphasing the dual foveas in avian retinas. It is difficult to know how to relate this to human trichromacy. But I would like to suggest that the problem of multiple dimensionality need not be such a problem for human objectivity as Matthen asserts. I would like to emphasize anthropocentrism in conjunction with Kim's (1993) notion of local reductions. Thus the physicalist explanation of human colour vision can be made independently of other species. Likewise, I wish to down-play Matthen's emphasis on opponent processing. My earlier arguments about opponent processes (Chapter 4) suggests that there is more of a relation between external features and physiological mechanisms than what Hardin allows.

Why does Matthen (1999) propose pluralistic realism compared with his previous theory of spectral reflectance? He wants to emphasize a plurality of mind-independent properties rather than just one, e.g. spectral reflectance. He emphasizes avian vision and in particular the observation that pigeons might be able to detect direction in flight by colour vision using ultraviolet light. Thus reflectance can't play a role in this discrimination. Matthen (1999) says:

> it is hard not to notice that in the human case, too, color experience does seem to gather in a heterogeneous collection of spectral emission properties..... reflectances, to be sure, but luminances and transmittances as well, for lights and stained glass windows seem not only to be seen in color but to be experienced in ways that are comparable, in exactly above sense, to the way in which surfaces are experienced..... not all of our colors are reflectances, not all colours are properties of surface. Not every color of which we are aware is even located..... the blue of the sky has a direction (like the pigeon's ultraviolet?) but no obvious location. Is it not wishful thinking to suppose that all colors we perceive can be accommodated in reflectance space? And if human experience detects all of

these different kinds of property, how can we be so sure that direction is not colored? (p. 64).

These arguments are similar to ones made by Campbell (1993) against reflectance theories.

Overall, I like the concept of pluralistic realism as a description of colour, but I wish to emphasize multiple mechanisms based on photon energy / wavelength as a basis of such a description, rather than depending on the visual phenomena I have discussed and other species colour system as Matthan does.

11.3 A Simple View of Colour

John Campbell (1993) has proposed what he calls a simple view of colour. He claims three things about colours: (1) colours are mind-independent properties of objects (p. 258); (2) colours are the grounds of the dispositions of objects to produce experiences of colours (p. 258); (3) colours are properties whose real nature is transparent to us in colour experience (p. 258). Despite this assertion of mind-independency, Campbell states that:

> This is not a kind of physicalism about colours. To suppose that it must be is to assume an identification of the physical and the objective which the thesis may question. It may instead be that the characters of the colours are simply transparent to us "(p258).

Campbell later says that:

> one explanation we might give of colour perception is in terms of wavelengths and physiology. But on this view, to suppose both explanations are correct would be to suppose that colour-experience is causally over determined. The only reasonable alternative is to take the colours to be epiphenomena. (p. 262).

This is a most unusual conclusion for someone taking an objective view of colour being mind independent. It would seem to me that any objective account of colour would need to explain both the stimulus side and the physiological side of colour perception. Byrne and Hilbert (1977c) have described this form of realism about colour as primitivism. According to them, primitivism says that colours are not dispositions, but no reductive analysis of colours is possible, whereas physicalism says that they are physical properties. J. Campbell (1993) argues that his simple view of colour says that:

> redness, for example, is not a disposition to produce experience in us. It is rather, the ground of such a disposition. But that is not because redness is a microphysical property..... the real nature of the property is, rather, transparent to us. This view of colours would be available to someone who rejected the atomic theory of matter: Someone who held that matter is continuous and that there are no microphysical properties. The view of colours as mind-independent does not depend upon the atomic theory. Nevertheless, without there being a commitment to any thesis of property identity, someone who holds this simple view may acknowledge that colours are supervenient upon physical properties, if only in the minimal sense that two possible worlds which share all their physical characteristics cannot be differently coloured. (p. 258).

Byrne and Hilbert (1997c) say that:

> Primitivists agree with physicalists that objects have colors, and that these properties are not dispositions to produce perceptual states. But they also hold that colors are *sui generis*, and so they deny, in particular that colors are identical with physical properties (p. xii)

Michael Smith (1993), in a following chapter to Campbell, has some very critical things to say about the simple view of colour. He points out that Campbell does not explicitly give an account of what it is for a categorical property to ground a colour disposition. Smith argues that Campbell offers some hints of how this might be achieved. Campbell says:

> Suppose... that a round peg fails to enter a round hole. We explain this by saying the peg and board are made of a rigid material, and that the diameter of the peg is greater than that of the hole. This is not an explanation in terms of basic physics, but it is a causal explanation. And there is no reason to suppose that the roundness and size of the peg are

anything other than the categorical properties of it. Equally, when we explain an experience of redness by appeal to the redness of the object seen, This may be a causal explanation though it is not at the level of basic physics, and even if the redness is not a disposition or a functionally defined property of the object (p. 263).

By this example, Campbell hopes to overcome by showing how explanations at the level of the supervening properties can themselves be causal explanations or " how there can be more than one "explanatory space" if all causation is physical causation" (p 263). As Smith (1993) points out this model for what it is for colours to ground the disposition of objects to look coloured depends on colour being an ordinary categorical property like shape and size. But these are categorical properties because they can be measured. Smith (1993) asks:

> what i.; the analogue of this kind of cannonical method (e.g. measurement) in the case of colour? More to the point, what is the analogue if the ' real nature' of colour is supposed to be 'transparent' to us in colour experience: that is, if ordinary perception is supposed, in this way, to reveal everything there is to know about the nature of colour? There is simply no analogue. Facts about colour thus seem not to be independent of facts about colour appearances in the way required to make the model work. (p. 272).

This transparency or revelation thesis will be addressed in detail in Chapter 16.0 and shown to be an inadequate account of colour, because there are important aspects of colour that depend on physical mechanisms that transparency cannot reveal. And as Smith also points out, it cannot handle the topics of colour illusion and unperceived colour. Smith (1994), by the way, supports a dispositional view of colour.

It is interesting that Campbell (1993) does not mention Jackson and Pargetter's (1987) arguments against a dispositional account of colour, in which they argue for a categorical account. An account that is based on potential physical mechanisms underlying a mind-independent thesis about colour. I would like to argue that my PE/W mechanism provides a categorical basis for colour in that quantum effects (e.g. interactions with electrons, etc). Provide a broad wavelength account of colour. Overall, I judge that Campbell's sui generis approach cannot be supported.

11.4 Tye's theory of colour.

Tye (1996a, 2000) has proposed a realist theory of colour. In his earlier book (Tye, 1996a), he discusses colour in the context of secondary qualities. He argues that colours and other secondary qualities present difficulties for his PANIC theory of consciousness. He argues that colours are:

> simply intrinsic, observer-independent properties of those objects and surfaces. We think of colors as inhering in the surfaces of objects (Tye, 1996a, p. 145).

He argues that the Lockean secondary quality view is not credible as it supposes that there is a basic illusion involved in normal experiences of colour, that colours are really (response-dependent) relational properties even though we experience them as nonrelational. Tye then argues that the best explanation of colour is Land's triple of reflectances. He argues that Land's theory can explain a number of problems for an objective account. These are the fact that spectral reflectances can vary but colour does not change and metamers can look the same colour even though the reflectances are different. He argues, without presenting any evidence, that Land's theory can explain these objections. He then mentions the problem of unique and binary hues, but he really has no answer to this issue. It is interesting that while Tye thinks colours are objective, he wants to argue that Land's theory shows that:

> once each tiny patch that is visible in the scene is assigned a color gradient, absolute colors are then computed by a further process (Tye, 2000, p. 164).

But this would seem to imply that colours are not out there but are computed in the brain.

In his latest book (Tye, 2000), he has dropped any mention of Land's work in his discussion of colour. Instead, Tye asserts that colour is related to surface reflectance, without going in to any detail about reflectance. For example, he does not analyse Hilbert's theory of reflectance at all. Tye (2000) starts his discussion of colour with a quotation from Cosmides and Tooby, 1995, p xi), which says that:

> far from being a physical property of objects, color is a mental property.... a useful invention that specialized cicuitry computes in our minds and then 'projects onto' our percepts of physically colorless objects. This invention allows us to identify and interact with objects and the world far more richly than we otherwise could. That objects seem to be colored is an invention of natural selection, which built into some species, including our own, the specialized neural circuitry involved . (p. xi)

Of course, I have noted similar arguments from a range of workers in the field of colour (Chapter 1.1), but this quotation is quite precise. Tye asserts that the approach of Cosmides and Tooby is like that of Hardin (1988) in that it interprets color experience as being a wide-spread and systematic error. Against this, Tye says:

> I want to defend the view that colors are objective, physical properties against the criticisms brought by Cosmides, Tooby and Hardin (Tye, 2000, p. 146).

Tye (2000) looks at the standard objections to colour objectivity. He says that:

> Cosmides and Tooby (C&T) adduce two considerations in defense of the view that colors are not mind-independent properties of external things (p. 150).

They are that we sometimes see physically indentical objects or spectral arrays as having different colours and that we routinely see physically different spectral arrays as having the same colour. Tye only looks at the second problem from the notion of colour constancy, but not from metamerism. He concludes that color constancy shows that:

•

> the color a surface has is not one and the same as the wavelength of the light it reflects under any particular illumination (p. 150).

While colour constancy is an issue for objectivism, I like to refer to the work of Helson and Jeffers (1940), who showed that if only a very small percentage of the dominant wavelength was reflected from an object under coloured illumination, then the object was perceived to have its daylight colour. This suggests to me that this wavelength objection is not so powerfull in natural conditions. Whereas, under unnatural conditions (e.g. Monochromatic light), I quoted MacAdam (1985) as showing that an object could be made to appear any colour, as only light of that wavelength would be reflected. This, in a way, supports a wavelength interpretation.

Tye (2000) looks at physically identical things appearing different colours in the general context of simultaneous colour contrast. Tye suggests that there are two possible conclusions. One is to agree with C&T that in some cases physically different objects do indeed have different colours. The other is to conclude that the perceived colour of a surface is relative to a surround. I support the latter interpretation as I suggested in Chapter 7.3 that, in a topical neutral context, simultaneous colour contrast can act like a real colour. Thus surround colour can evoke normal colour mechanisms that are normally elicited in the surrounded areas by physical colours.

Tye (2000) also examines Hardin's arguments that unique and binary colours refute objectivism. However, his arguments are rather weak and depend on assertions that opponent process theory is oversimplified. From this he asserts that colours are anthropocentric, but this does not make them subjective as Hardin (1988) wants to argue. A much more powerful argument against unique and binary hues refuting objectivism is provided by the work of D'Zmura (1991) and colleagues showing other detection mechanisms in central vision (see Chapter 4.1).

If one allows that the objections can be overcome by my suggestions, then what sort of objectivism is Tye proposing? He asserts that there are three theories about what he calls the common sense view of colour; e. g.

> the obvious view of color, at least as far as common sense goes, is that the colors we see objects and surfaces to have are observer-independent properties of those objects and surfaces (Tye, 2000, p. 147).

The three possible positions concerning the nature of color are: emergentism, brute nonreductive physicalism and reductive physicalism.

Emergentism is the view that colours are simple qualities, distinct from any of the qualities posited by science. He says that:

> these qualities happen to emerge once certain scientific properties are instantiated in things. They are nomologically linked to the scientific properties, but the relevant laws are not metaphysically necessitated by the microphysical facts and laws. Thus, the emergentist concedes that there is a possible world just like the actual world microphysically bu' in which objects have different colors from those they actually posses or even no colors at all (Tye, 2000, p 148).

Thus for the emergentist, there is no difficulty reconciling modern science with common sense about colour. Colour just is not the sort of quality that science investigates. He says that:

> the various hues (or at least the unitary ones) are simple qualities whose natures are wholly given to us in sense experience. They are no more than they appear, and since they appear to be mind-independent qualities, that is what they are (p.148).

Tye argues that a decisive difficulty for emergentism is that it makes colours causally inefficacious. He says that:

> if colors might have been different or missing while the microphysical facts and laws remained the same, then which colors objects have or indeed whether they have any colors makes no difference to their physical interactions (p. 148).

He argues that this is intuitively false in that colours can act as causes and says that:

> moreover, if colors make no difference to how light is reflected from objects, to the subsequent changes at the retina, in the optic nerve, and so on. Then it follows that we do not see colors! That seems absurd. Worse still, if we do not see colors, then, intuitively, we do not see things at all. Intuitively, we see the surfaces of things by seeing colors (p. 149).

This view of emergentism is a rather radical form of revelation discussed in Chapter 16.0.

For Tye, brute nonreductive physicalism differs from emergentism in one respect. It is now denied that there is possible world just like our world microphysically but differing from it with respect to the distribution of colour. Tye says that:

> for the brute nonreductive physicalist, there are synchronic bridge laws that link the microphysical realm with color. But these bridge laws are themselves metaphysically necessitated by the microphysical facts and laws. They obtain in all possible worlds that are microphysical duplicates of our world (p. 149).

Tye now develops a complex argument against this position. He says that this position solves the problem of causal efficacy for colours, but it does so by creating another deep problem. The bridge laws are epistemically basic yet they are metaphysically derivative (determined as they are by the microphysical facts and laws). He says that:

> this seems implausible. Everyone agrees that some laws are epistemically basic—in particular the fundamental microphysical laws—but to claim that there are laws that are epistemically basic and metaphysically derivative is to adopt a seemingly unstable position. If laws are metaphysically derivative, then surely it cannot just be a brute fact that they obtain in the range of possible worlds that they do. Surely there must some explanation "(p. 149).

Tye (2000) decides to adopt reductive physicalism or the view that colours are physical properties whose natures are discoverable by empirical investigations. He says that:

> on this view, the synchronic bridge laws connecting the microphysical realm to color are both metaphysically derivative and epistemically non-basic. They obtain in all possible worlds that duplicate our world micophysically and there is an explanation as to why this should be so—an explanation that allows us to understand how microphysical facts necessitate the facts about color (p. 149).

While I sympathize with this view, Tye does not examine any of the problems for such a reduction. For example, the arguments of Westphal (1991) that I will discuss in detail in Chapter 12.3.5. Overall, Tye does not give a detailed, strong account of his objective theory and his arguments depend on the colour processes I have been discussing.

11.5 Ross's Theory of colour

Ross (2000, 2001a) has put forward a realist theory of colour that is based on Smart's (1975) disjuntive theory of colour. Ross (2000) focuses on the constituting nature of the colours, which we attribute to physical objects in virtue of our visual experiences of colour. He argues that there are five most common answers to this problem:

(1): Subjectivism: colours are mental properties, processes, or events.

(2): Physicalism: they are physical properties of objects.

(3): Dispositionalism: they are dispositions of physical objects to produce visual experiences of colour.

(4): Primitivism: they are sui generis properties of physical objects (Campbell, 1995).

(5): Impressionism: they are sui generis properties of physical objects (McGinn, 1996).

I have discussed Campbell's views in Chapter 11.3 and I will discuss McGinn's views in Chapter 16.0. Ross (2000) distinguishes two versions of physicalism: disjunctive and nondisjunctive. He says that both versions are worth defending because they have two virtues:

> (a) consistency with an explanation of our perception of colors as located on the surfaces of physical objects in terms of colors possessed by surfaces.
>
> (b) consistency with the naturalization of color, that is, an explanation of color in nonchromatic (for example, physical or neural) terms (p. 109).

Ross argues that each of the other common proposals about the constituting nature of colours lacks at least one of these virtues. He claims that subjectivism lacks (a) because it claims that perceived colours are mental properties, processes, or events. Therefore, it must explain how we perceive colours as located on the surfaces of physical objects even though surfaces are colourless. Ross argues that:

> there's currently no plausible way to explain our perception of colors as located on the surfaces of objects except in terms of colors possessed by surfaces (p.109).

He says that subjectivism's options for this problem appear to be limited to either a sense datum theory of perception, which holds that colours are properties of mental objects, namely, sense data, or a projectivist theory of colour perception which holds that colours are mental processes or events, rather than mental properties of sense data. These properties are projected onto mind-independent objects. It would seem to me that both sense data and mental processes could be projected. However, we have no idea of a projection mechanism, as I mentioned earlier in connection with Armstrong's views.

Ross (2000) also argues that:

> Primitivism and impressionism lack (b) because both hold that colors are sui generis properties of of physical objects, and thus are not explainable in nonchromatic terms. The current standard version of dispositionalism also lacks (b) because it holds that colours are constituted

by dispositional relations between physical properties of physical objects and color qualia, where color qualia are mental qualitative properties of visual experiences which are what it's like to be conscious of colors. Such mental qualitative properties supervene on neural processes or events but cannot be explained in neural, or any non-qualitative terms. (p.110).

Ross (2001a) argues for disjunctive realism largely on the basis of Hardin's (1988) arguments about metamers, opponent processes and unique hues. He says:

> that each determinate perceived color is realized by a disjunction of physical properties. Physically distinct properties that are perceived as the same determinate colors are called Metamers (p. 107).

In this thesis, I have argued that metamers are not seen in the natural world and therefore I wish to argue for a non-disjunctive version of physicalism, without the need to postulate a disjunctive set of reflectance properties underlying determinate colours in the natural world.

Although Ross argues that there are two main versions of subjectivism which handle how colours are located on objects, e.g. sense data and projectivism; he also proposes later that there are three versions of subjectivism. Two versions of subjectivism hold that the visual field is an array of mental impressions. These versions are sense datum and adverbial subjectivisms. Sense datum theory says that sensing is a relation between a perceiver and sense data, which are mental objects. That is, sensed colours are mental properties of mental objects. Jackson (1977) has argued that these mental objects are located in physical space, thus we perceive physical objects and properties in virtue of a mental medium, namely an array of physically located mental objects. This proposal is why I put this theory in the dualist / subjectivist cell in Table 3. It is still a mystery to me how a mental object can be physically located in space. Fortunately, Jackson no longer holds this theory.

Ross (2001a) argues that adverbial subjectivism claims that perception is a non-relational way that a perceiver is. That is, there are no mental objects, instead sensed red is to be understood in terms of a kind of mental processes or events of perceivers, which can be identified with neural processes. Thus sensed red can be referred to by an adverb 'redly'.

Ross (2001a) puts forward a scientifically motivated argument for subjectivism, which he derives from Hardin (1988). The premises of this argument consist of a pair of claims made by visual scientists and a philosophical assumption:

First claim made by visual scientists: (1a) Our ordinary colour categories in no way correspond with, and are not explained by, physical categories.

Second claim made by visual scientists: (1b) our ordinary colour categories do correspond with, and are explained by certain neural processes of the human visual system.

Philosophical assumption: (2) Colours are identified with a range of properties which correspond with and explain our ordinary colour categories (the corresponding category constraint)

Subjectivist conclusion: (3) Thus colours cannot be identified with physical properties of objects, but rather are identified with neural processes of the human visual system.

Ross (2001a) says that claim (1a) is an uncontroversial finding of visual science and bases this on the fact that for any determinate colour there are indefinitely many metamers. Thus there is a disjunction of different physical properties capable of producing a colour. Claim (1b) is based on Hardin's arguments about opponent processes etc. Ross (2001a), like me, also cautions that Teller (1991) asserts the neural processes that realize opponent processes have not yet been found. Of course, I claim that metamers are not so important as they don't appear in the natural world, but are artefacts of visual technology of pigments and dyes and electronic processes.

The main argument of Ross is about the philosophical assumption 2. He wants to assert that the "corresponding category constraint" should be rejected on rather unusual grounds. He says that there are claims that:

> I must identify ordinary color categories and colors merely assumes the corresponding category constraint. In my usage, the term " ordinary color categories " is just a shorthand for the relations of qualitative identity, difference, and similarity among colors..... namely the relations which are represented in the psychological color space. These categories are neutral with regard to whether colors are physical, mental, or some other property or process. Furthermore, since the basic issue is to show that some proposal about the constituting nature of color, for example, subjectivism or physicalism, is the correct one, we must be allowed to refer to these categories in this metaphysically neutral way (Ross, 2001a. p. 154).

He goes on to say that while the ordinary colour category red is merely a region of the psychological colour space, the colour red is some property such as a disjunctive property (or a functional property or some other property). This would appear to me to be a rather odd conception of colour. Surely, the psychological colour space is one way to identify colours with physical variables mediating colour, as systems, such as the CIE, can produce matching colours across different laboratories without direct human input. I would argue that the colour red is both a non-disjunctive physical property and a related category in psychological colour space. (see Chapter 15.0 for a more detailed account of colour spaces).

Ross (2001a) lays great stress on the location problem for colour subjectivism, He is concerned not only with the constituting nature of sensed colours, but also with sensed location or what he calls " the constituting nature of the visual field " (p. 47). He argues that subjectivists must indicate how mental colours are experienced as spatially located. As I mentioned above, he examines what he calls the three versions of subjectivism about colour and the constituting nature of the visual field. He dismisses sense datum subjectivism because people such as Jackson (1977) have argued that sense data are non-physical properties located in physical space. Ross (2001a) says that:

> sense datum subjectivism is not a tenable option for scientifically motivated subjectivists who hold that colours are mental processes or events which are identified with neural processes or events (p. 52).

He argues that adverbialist subjectivism should be rejected as it cannot handle the many property objection put forward by Jackson (1977). In addition, Jackson (1976) argued that if adverbialism asserts that images are a part of the visual field, then this commits the adverbialist to the existence of a species of mental object, namely, parts of the visual fields, and so undermines the whole rationale behind the adverbialist theory.

The third form of subjectivism that Ross examines is the virtual colour proposal of Maund (1995), who argues that colours are merely represented or virtual colours. I will examine Maund's theory in some detail in Chapter 15.0. Ross argues that the virtual colour concept ends up being a version of adverbialism and is thus open to the same objections. Ross argues that virtual colours take the form of an eliminativist argument:

> having defined sensed colors in a certain way, and finding that nothing has sensed colors so defined, he (Maund) concludes sensed colors do not exist (p. 53).

However, Ross does not realize that Maund (1995) regards his virtual theory as being nihilistic. Maund says that: " the theory of virtual colours would be a form of colour nihilism" (p.103). This means that there are neither physical nor subjective forms of colour. Thus it would appear to me that virtual colours are not a good account of colour.

Ross (2001a) now has an unusual theory about colour. He states that:

> My positive proposal is that sensed colors are disjunctive physical properties. This leaves open the possibility that visual experiences have sensory qualities, namely neural processes which explain our ordinary color categories, which are not identified with the qualitative aspect of color experience.......they are qualities in that they explain our ordinary color categories, not by virtue of being the colors we sense, but by providing

perceptual access to the colors we sense .... I hold that the qualitative aspect of color experience is a physical property of physical objects and so is outside of the head (p.151).

This twofold classification of sensed colours and sensory qualities which allow us perceptual access to the sensed colours is difficult to accept as a physicalist theory.

Ross (2000) uses Campbell's (1969) distinction of transitory and standing colours, except he calls transitory transient. Ross points out that Hardin (1983) argues against both dispositionalism and realism because both must characterize veridical colours of physical objects as relative to standards. Hardin argues that physical objects look grossly different transient colours relative to different types of perceivers and different viewing conditions. But if colours are properties of physical objects, as standardizing realists claim, then there must be a principled characterization of each object's veridical colour. On the basis of the colour phenomena I have discussed Hardin claims that standardizing physicalism can't make this distinction, because all transient colours are real mental processes and events incorrectly attributed to physical objects.

Ross's reply to this is to say that:

> Disjunctive physicalism, as a version of standardizing realism, adds that an object's veridical color is its transient color relative to certain favored conditions of perceptual access, and so characterizes veridical color independently of any specification of the physical nature of color. (Ross, 2000, p. 114).

This is an odd conclusion for any form of physicalism in that veridical colour is independent of the physical nature of colour. Ross (200) asserts that:

> According to disjunctive physicalism, transient colors are physical properties accessed by complex relations........ descriptions of these complex relations constituting perceptual access---- the causal relations between physical colors and perceivers' visual systems--- are merely reference fixers and don't specify the constituting nature of color. (p 121-122).

Ross finally admits that;

> Colors are complex relations between perceivers and objects perceived. I think their claim that colors are relations gets a fundamental point right. (p. 122).

This relational account is taken up by Thomas (2001), in a review of Ross (2001). He points out that Ross's distinction between "sensed colours" and " sensory qualities" is essentially the same as Locke's distinction between secondary qualities, as powers in objects and the ideas of these qualities (the qualitative experiences) as they occur in our minds. This is hardly the basis for a form of physicalism.

I would argue that a non-disjunctive physical theory like PE/W theory in which a direct realist account is provided and which does not depend on the colour processes that I have discussed, is a better type of physicalist theory than Ross's one.

11.6 Summary of these objective views

Overall, I don't think that the five realist accounts of colour discussed in this chapter are adequate. Mostly, they fail to address the most important objections, such as those of Westphal (1991) to reductive physicalism, or if they try, as Tye (2000) has done, they do it inadequately. They mostly refer to the arguments about visual processes that I have examined already. I think that the arguments I have mounted in earlier chapters give better accounts of the problems of unique and binary hues, of metamers, and of surround conditions such as simultaneous contrast. I regard my theory of a photon energy / wavelength explanation of colour as providing a stronger physicalist account of colour.

CHAPTER 12.0

12.1 Some Objections to the Primary Quality Thesis

There are many philosophers who argue strongly against a primary quality account of colour. They are set out in Table 3. We plan to look at as many of these as possible.

12.2 Johnston and how to speak of the colours

Johnston (1992), in an important paper, has argued strongly against a primary quality account of colour. Johnston (1992) starts off with what appears to be an odd proposition about colour. He says:

> It seems to me that the philosophy of color is one of those genial areas of inquiry in which the main competing positions are each in their own way perfectly true. For example, as between those who say that the external world is colored and those who say that the external world is not colored, the judicious choice is to agree with both. Ever so inclusively speaking the external world is not colored. More or less inclusively speaking the external world is colored (Johnston, 1992, p. 221).

Gold (1999) has argued that this proposition is Johnston's attempt to solve what Gold calls the central problem of colour. One issue is whether colour can be identified with a physical property of the external world i.e. a realist account; or whether colours are either illusory or are identified with states of the mind or brain, i.e. an antirealist account. Gold says that Johnston's dispositional approach is supposed to agree with both the realist and the antirealist and offer a truly synthetic account of colour The disposition is the external factor and the manifestation or sensation is the internal factor, thus colour is in the world and not in the world. The following analysis by Johnston would, perhaps, dispute that conclusion, as Johnston says clearly that

> As between those who say that the world is colored because colors are primary qualities and those who say that the world is colored because colors are secondary qualities the judicious choice is first to agree with neither, then to agree with both and finally to agree with the friends of the secondary qualities (p. 228).

I find it hard to see Gold's synthesis of the central problem here.

Speaking inclusively for Johnston is employing a conception of colour that underwrites all core beliefs about colour. He says that the external world fails to be coloured ever so inclusively speaking because not all the core beliefs about canary yellow, for example, can be held. Johnston (1992) identifies five beliefs about colour (taking canary yellow as an example) to be one way of understanding our core beliefs about colour. They are:

(1) paradigms: some things we take to be paradigms of canary yellow things (such as some canaries) are actually canary yellow.

(2) explanation: something's being canary yellow causally explains visual experience of a canary yellow thing.

(3) unity: canary yellow, like every other shade, has a unique place in the network of relations among colours.

(4) perceptual availability: we are justified in concluding that something is canary yellow just on the basis of our visual experience (with the qualifications to the effect that the perceiver is normal and the conditions adequate for forming colour judgements)

(5) revelation: the nature of canary yellow is completely revealed by standard experiences of canary yellow things.(I will discuss revelation in more depth in a later chapter, which focuses on this problem.)

Johnston (1992) argues:

> Why should we admit that the external world is not colored ever so inclusively speaking? Well, given what we know from the psychophysics of perception it follows that Revelation and Explanation cannot be true together. For when it comes to the

> external explanatory causes of our color experiences, psychophysics has narrowed down the options. Those causes are either non-dispositional microphysical properties, light-dispositions (reflectance or Edward Land's designator dispositions or something of that sort) or psychological dispositions (dispositions to appear colored) with microphysical or light- dispositional bases. Explanation therefore tells us that we must look among these properties if we are to find the colors. Revelation tells us that the nature of colors are.... *laid bare* in visual experience. The nature of canary yellow is supposed to be fully revealed by visual experience so that once one has seen canary yellow there is no more to know about the way canary yellow is. (p. 224-225).

Johnston concludes from this that the natures of non-dispositional microphysical properties and the surface reflectance properties in play in visual experience are not revealed or laid bare by pure visual experience. Hence these properties do not satisfy Revelation:

> Hence, ever so inclusively speaking, no such property can be canary yellow. Mutatis mutandis for the other colors (p. 225).

Johnston does not come to a similar conclusion about dispositions which he calls a secondary quality account:

> the same point cannot be decisive against identifying the colors-as-revelation-represents-them-as-being with dispositions to look colored (p. 226).

Johnston has argued that although a form of dispositionalism can preserve many of the core beliefs, it can't preserve them all. Especially, it can't preserve revelation. Johnston (1992) argues for a form of response dispositionalism based on what he calls 'constituted dispositions'. These are defined as:

> a higher-order property of having some intrinsic properties which, oddities aside, would cause the manifestation of the disposition in the circumstances of manifestation. (p. 234).

Johnston asserts that response-dispositionalism as a secondary quality account does better than a primary quality account on revelation, unity and perceptual availability, and no worse on explanation.

Johnston replies to Jackson and Pargetter's (1987) objection to traditional dispositionalism. They argue that a physicalist account is preferable to a dispositionalist account because intrinsic physical properties are better explainers than dispositions (which are higher -order properties) in virtue of being more scientifically basic. However, Johnston argues that the physicalist account is also at one remove from explanation just like dispositions. This is because the physicalist account is that colours are disjunctive properties, i.e. the relevant property does not figure directly in the explanation of the colour appearance, but only as a constituent of the explanatory property. Thus the appeal to dispositions is no worse off than the physicalist form of explanation. The physicalist has to appeal to disjunctive properties; the dispositionalist has to appeal to higher-order properties. Thus Johnston claims that his form of dispositionalism is the approach to adopt. (note the weight being put on the disjunctive account of colour which we are contesting).

There are a number of objections that have been put forward against Johnston's views about revelation. Jackson (1996) agrees that if colours are transparent as revelation suggests, then the primary property view must be false. Jackson asks whether revelation is really part of the folk theory of colour. He gives three reasons for denying that it is:

(1) He finds it is hard to believe that our experience of colour is that different from our experience of heat. Before we knew what heat was, we probably said that the sensations of heat revealed the full nature of heat, that

> heat is precisely that which is fully transparent to us when something feels hot. After all that was the main thing most people knew about heat, just as the main thing that is currently common knowledge about redness is that it makes things look red (thus, the intuitive appeal to revelation). However our very prepardness to identify heat with molecular kinetic energy when the empirical evidence came in shows that this opinion

was merely opinion. We did not hesitate to identify heat with something whose full nature is manifestly not given to us in the experience of heat (Jackson, 1996, p. 210).

I believe that our theory that colour is explained by the broad tuning of PE/W mechanisms, is in the same position as heat, because it suggests that disjunctive colour properties are not readily available in the real world and thus PE / W gives us a simpler type of explanation, in that it is not necessary to make fine distinctions between coloured stimuli with many crossings in the spectra. Thus, revelation would not be part of the folk theory of colour.

(2) Jackson (1996) points out that colour illusion is possible, thus one can draw a distinction between colours as they really are and colours as they appear to be. Jackson points out that this shows that colours have natures that outruns our experiences of them, as revelation implies.

Jackson (1996) argues that the prime intuition of his approach:

> requires our experience of colors as typically caused by color, and it is part of the folk notion of causation that causes and their effects are distinct. But if our experience of colour is distinct from what it is an experience of, how could it transparently reveal the nature of colour? The folk thus know something about color that tells them that revelation could not possibly be true. (p. 211).

I regard Jackson's three points as being strong arguments against a revelation position. I propose to give another argument against the transparency of revelation, below and in Chapter 16.0.

Johnston (1996), in a later paper, entitled 'Is the external world invisible?' expands on his earlier paper and reveals a possible subjective approach to perception which does not fit in with Gold's (1999) interpretation of Johnston arguing that colour is both in the world and also a subjective property. Johnston says:

> despite the seductive offer that perception makes, we cannot take our perceptual experiences to reveal the natures of external

things......perceptual experience does not reveal the nature of its causes. In other words, it does not acquaint us with the external features causally responsible for our experiences but only with their effects in us.....The originally unbelievable conclusion now follows: we cannot see color, because our visual experience as of colors of things do not reveal to us what the colors of the external causes of our experience are like. But if we do not see color we do not see color difference, and if we do not see color difference, we see neither edges nor colored areas, and if we see neither edges nor colored areas, we do not see surfaces, and if we do not see surfaces, we do not see anything in the material world. Our visual experience is then just a ' false imaginary glare', simply an arbitrary medium in which the material world is mapped for the purposes of intentional action. The characteristic pleasure of seeing, the pleasure of having the nature of visible properties and visible things revealed to us, is a false pleasure. The promise of vision now appears totally fraudulent. (p. 187-191).

This is surely a strong subjective or sense data account of perception; a very radical secondary quality account with the quality entirely subjective; it hardly denotes colour being in the world.

In this later paper (Johnston, 1996), Johnston raises another issue which is difficult for his earlier views on dispositions giving acquaintance with colours. He argues that response-dispositions come in pairs:

> That is, whenever there is a disposition of some external object or objects to produce a sensory, emotional or cognitive response in a class of subjects under certain conditions, there is also the correlative or dual disposition of the subjects in question...so as well as the apple's disposition to look red to me, there is my disposition to have an experience as the apple looking red when the apple is presented—so the same response is potentially as much a revelation of a dispositional property of mine as it is a revelation of a dispositional property of the apple. (p. 197).

This would appear to make it difficult for colour perception to be able to reveal actually where colour is located. I discussed this concept earlier in Chapter 2.0, in considering the concept of reciprocal dispositions proposed by Martin and Heil (1998).

In a series of visual experiments (Webster et al., 1992), I am able to provide strong evidence against Johnston's claim about perception not revealing some features of the external world. These experiments will be discussed in more detail in a later chapter on revelation (Chapter 16.0). Kelly (1976) showed by mathematical analysis that spatial frequency analysis could be extended to stimuli with two-dimensional luminance profiles, such as checkerboards. Kelly (1976) showed that there is no Fourier energy parallel to the edges of checkerboards; rather, the energy is located at the orientation of the fundamental and harmonic frequencies of the checkerboard spectrum. Thus a checkerboard with vertical and horizontal edges has its energy at orientation of the fundamental at 45° and 135° and for example, at 18° and 108° for the third harmonic. In our experiments, we showed that a coloured orientation after-effect was located at these orientations rather than at the visible edges. Thus, the experimental perception confirmed and supported the mathematical analysis of how energy was located in the physical world. It is clear from this that experimental studies of perception can reveal to us some of the causal factors in the physical world. It also shows that the nature of colours in relation to energy outruns our experience of them, since our simple introspection would mistakenly locate the energy at the vertical and horizontal orientations that we perceive. (I will give a more detailed account of these experiments and their relation to revelation and transparency in Chapter 16.0. This will involve some repetition of the work cited here).

The next question is how our experimental results bear on Johnston's account of dispositions and its relation to the views of Prior, Pargetter and Jackson (1982), Jackson and Pargetter (1992) and Jackson (1996)? Johnston (1992) says that:

> vision can acquaint us with the natures of the color properties if these properties are dispositions to produce visual responses. The similarities that color vision reveals will then be visually apparent

similarities among the colors, not mere similarities among the visual appearances which the colors, whatever they might be like, cause. There will be, after all, a grain of truth in Revelation- visual experience taken, not naively, but as a series of manifestations of visual-response dispositions, can acquaint us with the nature of colors. (p. 163).

However, the results with two-dimensional (2D) luminance profiles indicate that colour in a one-dimensional luminance profile (e.g. a grating) is based on energy aligned with the edges, whereas the 2D colour aligns not with the edges, but with the energy of the checkerboard spectrum. Yet the colours appear the same, thus dispositions to produce sensations of colour, as Johnstone would claim, don't necessarily reveal the nature of colours in this situation. That is, apparently identical colour properties have different physical properties when produced by either the checkerboard spectrum or the grating spectrum. Thus, different physical mechanisms produce the same appearance. DeValois et al., (1979) supported the concept of a different mechanism by single-unit studies of primate visual cortex. They found cells that responded to edges of gratings would not respond to the edges of checkerboards, but would respond when aligned with the orientations of the fundamental and the third harmonic.

These results are also difficult for the physicalist proposal of Jackson and Pargetter (1992) and Jackson (1996), in which they argue against a dispositionalist account of colour. They propose instead that colour is based on Land's three reflectance triples. The data of Webster et al., (1992) and DeValois et al., (1979) clearly indicate that cells sensitive to all three of Fourier spatial frequency, colour, and orientation are mediating these effects. There has been no evidence of a cellular model for Land's theory, in fact, as mentioned earlier, the cells predicted by Land's theory have not been seen yet (Livingstone and Hubel, 1984), and certainly no Fourier spatial frequency, orientation, and colour sensitive cells with receptive fields organized as the required R+ R- type of receptive field pattern for Land's theory.

Overall, I believe that Johnston's espousal of colour being based on dispositions receives less support than a physicalist realist approach. There are other problems with dispositions, such as circularity, which will be taken up in later sections.

12.3 Boghossian and Velleman's Subjective theory

12.3.1 The circularity argument

Boghossian and Velleman (1989,1991) (B&V) have argued that colours are not in the world, but are subjective and are projected onto objects in the world. In their first paper, they look at colour as a secondary quality. They commence by putting Galileo's argument that grass is not green. They say that:

> Galileo seems to have found it very natural to say that the property an object appears to have, when it appears to have a certain colour, is an intrinsic qualitative property which, as science teaches us, it does not in fact possess (p. 81).

They then point out that many theorists tend to recoil from this ascription of such massive error. For example, Shoemaker (1990) writes:

> Since in fact we apply color predicates to physical objects and never to sensations, ideas, experiences, etc., the account of their semantics recommended by the Principle of Charity is one that makes them truly applicable to tomatoes and lemons rather than to sense experiences thereof. (p. 110).

B&V (1989) don't think that charity should be applied in this way. They say that:

> Charity to visual experience is therefore no motive for resisting the natural, Galilean response to a scientific understanding of light and vision. The best interpretation of colour experience ends up convicting it of widespread and systematic error. (p. 81).

In this paper, they look at two familiar interpretations of visual experience as satisfying the principle of Charity. They are the physicalist and the dispositionalist accounts of colour. I will delay looking at their physicalist account until I look at their second paper (Boghossian and Velleman, 1991).

In B &V (1989), they assert that a disposition to look to be a colour has the following biconditional form:

> D3: Red (i.e., the property that Objects are seen as having when they look red) = def : (a disposition to appear red under standard conditions)

They then go on to assert that this biconditional D3 is viciously circular. They say that:

> Suppose he (the dispositionalist) says that 'red' expresses the same property on the right side of (D3) as it does on the left. In that case, the dispositionalist's account of colour experience is circular, since in attempting to say what property things appear to have when they look red, he invokes the very property that is at issue. (p. 87).

This circularity argument is very important and there have been many attempts to address it (Armstrong & Malcolm, 1984; Smith, 1994; Watkins, 1994; Tye, 1996a; Miller, 1997). Watkins (1994) points to an important distinction between representational and intrinsic properties. He uses an analogy of comparing the perceptual content of a painting:

> If the painting is of Mr. Jones, then the representational content of the painting is Mr. Jones.... The painting does have nonrepresentational or intrinsic features to which we might focus our attention, however. For

instance, the painting has certain lines, paint, brush strokes, and so forth. The painting is not about lines and brush strokes." (p. 58).

He goes on to point out that we are aware not only of the representational content but also of non-representational features of our experience:

> We are also aware of the ' brush strokes' and the 'lines' of our experiences, the properties which mediate our representing something external to our selves. Put less metaphorically (perhaps), we are not only aware of an object's color, but also the way color looks to us. (p. 58).

Watkins (1994) argues that the distinction is important because representational properties pose no special threat to physical theories of mind. He points out that functionalism explains representational features of experience in terms of functional relations: " For a state to be a representation of Mr Jones is just for that state to be functionally related to Mr. Jones in the appropriate way " (p. 58). However, intrinsic properties of mental states, if they exist raises serious problems for all physicalist theories of the mind. (Lycan, 1996b)

Watkins says that:

> Barring a reduction of these properties to intrinsic physical properties of the brain... to countenance nonrepresentational features of experience is to countenance non physical properties. (p. 59).

Watkins regards a brain reduction as an unlikely possibility given beings with different physical make up might have the same experience. While this does not seem to me to be a major objection, Watkins argues that a dispositional explanation without intrinsic features is still open to the circularity argument.

Watkins suggests that a non circular analysis of colour can be made by referring to some intrinsic quality of experience. He cites Peacocke (1984) as suggesting this strategy. Peacocke's general strategy is that we need to distinguish between two different types of intrinsic property possessed by the experience one has when confronted by a red object under standard conditions. One type is the representational property of being as of a red object. The other is the sensational property of being red' in the region of the visual field in which the object is presented. Peacocke works with a triparite distinction between being red, being red' and looking red. Peacocke (1984) says we can define x is red as:

> x is disposed in normal circumstances to cause the region of the visual field in which it is presented to be red' in normal humans. (p. 375).

This definition is not circular since red' is not the same property as red, rather red' is an intrinsic property of one's visual field which, under normal conditions and for normal observers, is present in the area of one's visual field where the red object is presented. The problem with this is that it only informs us about red if we already know, among other things, what red' is. There are a number of problems specifying exactly what the concept red' is. For example, is red'ness the same property as redness? If Peacocke does not go as far as to deny the claim that colours are colours', he explicitly refrains from making it (Bigelow et al., 1990), when he states:

> These primed predicates 'eliptical'' and 'white'' should not be confused with their unprimed homonyms. In using the notation, we are not saying that experiences have colour properties or spatial properties. (Bigelow et al., p. 20-21).

Bigelow et al., (1990) point out that in most cases the property that the visual field represents an object having is different from any property which the visual field possesses itself. They give as examples: (1) a circular coin being represented as circular by a region of the visual field which is eliptical'; (2) a row of trees receding into the distance may be seen as a row of equally tall trees, while each occupies a different extent of the visual field; (3) in the case of colour, a white wall may look white through a piece of blue cellophane, although the wall is represented in a blue' region of the visual field. The last example is rather odd, as they claim that it shows that blue'ness and blueness are not the same property. Just what is blue'ness in this case if it is not somehow coloured blue?

Watkins (1994) suggests these primed qualities are intrinsic properties and could be qualia. If this is so, Watkins points out that we still need some way to correlate each quale with the relevant colour. He then points out:

> that if the only way to determine which property is blue is to know antecedently that certain objects are blue', then Peacocke's account is circular. What Peacocke needs, then, is an account of blue' which makes no appeal to blue. (p. 65).

Watkins thinks that the circularity can be overcome by picking out what blue' is by ostension. He admits that blue' cannot be ostended directly, it must be ostended indirectly by pointing out an instance of blue under normal conditions, e.g.:

> blue', then, is that property present in one's visual field when one looks at one of these... this 'tells' us what blue' is without circularity. (p. 65).

But can this form of ostension be the basis for dispositions? It introduces the concept of qualia, which Armstrong (1980) has strongly challenged, and as B &V (1989) have argued with a similar line to Armstrong that it would lead to absurd phenomenology:

> A veil of colours—like Locke's veil of ideas—would stand before or lie upon the scene being viewed. (p. 283).

It is rather odd to see B&V arguing like Armstrong when they want to assert an error or projectionist view of colour, which is surely very subjective. The ostension approach would also appear to have difficulty with arguments about spectrum inversion, but this problem will be examined in a later chapter.

Armstrong (Armstrong & Malcolm, 1984) is also worried about the problem of circularity, He says:

> a sensation of green is that which is apt to be produced in us by a green surface. We thus have a tight circle of the two concepts, each defined in terms of the other. This would not be a vicious circularity if we have an independent way of introducing the two together. But what is this way? The Lockean approach gives us no help. (p. 177).

Armstrong considers a number of ways of overcoming the circularity problem. First, he considers whether a causal theory of colour could be developed as a scientific theory. He suggests:

> we then define greenness as that which is apt for the production of sensations of greenness. And for a causal theory of sensations of greenness we simply pin our hopes on future science. (p. 178).

However, he can't see a possible way in which a non-circular theory of sensations could then be developed. He then considers the idea of reducing the secondary qualities (such as colour) to scientifically respectable primary qualities, e.g., reflectance properties of surfaces. Thus, there is no epistemological problem in how we become aware of colours:

> Coloured objects act on us in virtue of their colour, and create in us a perception of their colour. (p. 178).

However, this still leaves us with the problem of getting a grip on secondary qualities quite independently of our grip upon sensations of such qualities. To overcome this Armstrong says:

> I propose, to this end, what might be tagged a Gestalt theory. When in perception we are aware of colour, sound, smell, taste, etc, of physical things, then the qualities which we are aware of are complexes of physical properties. The perceived secondary qualities are primary qualities! But we are aware of them in a unified, Gestalt, manner, a manner which fails to reveal the primary nature of these properties. (p. 178).

Armstrong still feels that there are difficulties with this proposal. He considers whether colour perception could be likened to shape perception, where we can recognize shapes quickly without being aware of any shape formula or primary basis. He considers whether the mechanism might be a fitting with a template internally and whether secondary qualities might be objective complexes of primary qualities which are recognized in this primitive manner, e.g., by templates. But, he contends that while this might work with shape in that we still attribute a primary property, shape to the stimulus, even if indeterminately; it does not appear to work with colour. He says:

> : But when a surface looks green to me, I am not attributing the corresponding primary quality or, indeed, any primary quality. Yet I am attributing a property to the surface which is different from the corresponding primary quality. (p. 179).

Armstrong (Armstrong & Malcolm, 1984) proposes that the way out of this difficulty is to have recourse to the topic-neutral manoeuvre. That is, we should attribute a property of some sort to the surface, a property detected by the eyes, but without any specification of the sort, thus leaving it open that the property is in fact a primary property. Armstrong (1973) then calls on the Headless Woman illusion to explain our inability to pick out that the quality involved is a primary quality. He says that it will look to the audience that the woman has no head, but he argues that:

> it is clearly invalid to argue from lack of awareness of the complex physical nature of mental processes and phenomenal qualities to the conclusion that we are aware that these processes and qualities lack this complex physical nature. The move from ' I am not aware that p' to ' I am aware that not-p' is a illegitimate shifting of the negation sign. (Armstrong, 1973, p. 191).

He says:

> our inability to pick out that the property is a structured property inevitably generates the illusion that it is not a structured property. (Armstrong, 1984, p. 179).

Although he believes this suggestion is on the right lines, he points out that it faces enormous phenomenological difficulties. While he thinks that there could be phenomenological advantages of locating colour on a surface and a topic-neutral account of the mental is reasonably plausible, it depends on the sensible qualities being extruded from the mind:

> But the sensible qualities themselves are the paradigms of concrete perceived qualities. How can a sub-class of these qualities, the secondary qualities, be treated as qualities we know not what, later identified, as a result of scientific considerations, with primary qualities? (p. 180).

Armstrong suggests that the illusion of concrete secondary quality is created because they appear to lack structure or any grain as W. Sellars (1963) puts it. But colours do have a huge multitude of systematic resemblances and differences to each other (the platitudes about colour, Smith, 1994). Each colour has a position in complex dimensional arrays of qualities and it is this immensely complex network of perceived resemblances and differences that largely creates the illusory impression that our acquaintance with the secondary qualities is acquaintance with definite qualities which are other than the primary properties.

Armstrong argues that resemblance is an internal relation and our awareness of the resemblances and differences of colour are sharper and clearer than in the case of other secondary qualities (e.g. platitudes like orange is between red and yellow). Thus it is colour which gives us the strongest impression of acquaintance with the concrete nature of the quality involved. Armstrong points out that:

> given our instinctive taking of resemblance to be an internal relation, a mere perception of resemblance suffices to generate the illusion that we have a concrete acquaintance with the qualities which sustain the resemblance. A perception of the internal relation of resemblance generates the illusion of a perception of intrinsic quality. (p.181).

Armstrong feels that the topic-neutral approach can be made to work to overcome this illusion making it possible to be able eventuallto identify colour with primary qualities and thus give no reason to bring secondary qualities within the mind "or give an analysis in terms of sensations of such qualities " (p. 181).

I support Armstrong's line of identifying colour with primary qualities, such as PE / W mechanisms, and not bringing the secondary qualities within the mind.

However, Armstrong (1973) realizes that there are difficulties persuading people that there is an illusion. He says that:

> a modern Materialist cannot remain content simply to assert that mental processes are nothing but certain sorts of physical processes in the brain. There remains the problem of ' phenomenal' qualities.... most conspicuously, the qualities apparently associated with bodily sensations and the perceptual ' secondary qualities'. Whether these qualities be treated as qualities of what is perceived (the Direct Realist view) or of the perceiving of what is perceived (the Subjectivist view), they are a problem for anybody who tries to give an account of physical phenomena purely in terms of the properties attributed to the phenomena by modern science and in particular modern physics......what the Materialist must assert is that phenomenal qualities are in fact ('can be contingently identified with ') complex properties of a sort which are respectable from the physicist's point of view. Mere perception and introspection do not enable us to grasp the identity of mental processes with brain processes. But it is vital to realize that in the case of the phenomenal qualities the identification is not like the identification of mental processes with brain processes. Both identifications are contingent identifications of properties. But the identification of the phenomenal qualities is not the identification of a feature previously specified only in terms of the causal role of things which have that feature. Identifying phenomenal properties is a matter of identifying a property grasped in a totalistic, holistic, unanalysed, way by sense and / or introspection, with a complex physical property either of the physical phenomena perceived, or of the brain (Armstrong, 1973, p. 181-182)

Armstrong (Armstrong & Malcolm, 1984) also points out that there may be problems in the case of the identification of colour with the physical because of the problems of metamers and whether primary properties are any more secure than secondary ones in terms of resemblances and differences. Thus, Armstong's position might appear rather difficult. However, if the views urged in this thesis are accepted, e.g. that metamers are not a problem and colour is largely based on interactions of photons with electrons depending on their energy, which leads to their broad spectra of wavelengths (Nassau, 1983). If this is so, then we will never be able to perceive the role of electrons as a part of any primary quality and we will be left with a topic-neutral account based on these mechanisms. In conclusion, we will have a physicalist explanation of colour based on the interaction with electrons which will never be perceived by a sensory system. Thus we will always have the illusion that colour is a perception of an intrinsic property. Armstrong (1996) speaks rather discouragingly of this intrinsic issue, when talking about Tye's (1996a) concept of representation as an account of qualia. He says:

> One difficulty for the programme Tye (Tye, 1996a, 'Ten problems of consciousness') is pursuing lies in the secondary qualities. The difficulty is not so much intellectual but, so I have found, just getting a hearing or even an understanding. A Lockean, or internalist, account of colour, sound, taste and smell seems to hold contemporary philosophers in a vice-like grip. The idea that these qualities are not in the head, but are instead where their phenomenology seems to place them, things or properties out in the world, arouses enormous resistance. (p. 3).

I agree with Armstrong about this vice-like grip on contemporary philosophers about phenomenology (see Table 3 for columns labelled Subjective and Lockean). I would support Armstrong's argument that these qualities should be treated as qualities of what is perceived (the direct realist view) and not as the perceiving of what is perceived (the Subjectivist view). I would argue that my proposed PE / W theory can be stated in these terms.

12.3.2 Boghossian and Vellman's argument from after-images

Bigelow et al., (1990) have analysed B&V's (1989) defence of a projectivist account of colour. They argue that the most intriguing argument starts from a consideration of the experience of seeing coloured after-images. They argue that if B&V are successful it would refute both the physicalist and the dispositionalist accounts of colour. According to physicalism, a colour is a physical property, perhaps the property of having a spectral-reflectance profile based on photon /

electron interaction. According to dispositionalists, having a colour is to have a disposition to cause visual experiences of certain kinds under standard conditions. B&V argue that each of these theories gets the phenomenology of visual experience wrong.

Bigelow et al., (1990) set out their account of B&V's analysis by supposing there is a yellow taxi in front of one and to the right....to the left of the taxi is a white wall, against which one can see a yellow after-image. The after-image is exactly the same shade of yellow as the taxi. Because the after-image is seen as yellow, and the the taxi is seen as having exactly the same shade of yellow, visual experience represents the taxi and the after-image as having the same colour property. However, B&V argue that the after-image is not a material object and is not seen as one. Bigelow et al., (1990) say:

> After-images need not be illusions. When you see an after-image you do not always seem to see a material object. Rather; visual experience may represent the after-image as a figment or projection of your eyes, something which is seen as existing only in so far as it is being seen. This, claim Boghossian and Velleman, spells trouble for both physicalism and dispositionalism. Something which is not perceived as being a physical object cannot be perceived as having a physical property or as possessing a human-stimulating propensity. So visual experience represents the after-image as the sort of thing that could not possess a spectral-reflectance profile, or a disposition to cause specified visual experiences. in a normal viewer, under standard lighting conditions. (Bigelow et al., 1990, p. 280).

B&V argue that it is impossible to represent the after-image as being non-physical and as possessing a physical property; hence yellowness is not a kind of property that a physical object could have. Thus when visual experience represents the taxi as yellow, the colour yellow must be a property of something other than the taxi itself. The colour yellow must be a property of the same kind as an after-image, and thus of something like a region of the visual field, the same property which characterizes the visual field further to the left where the after-image hovers (Bigelow et al., (1990). As Bigelow et al., (1990) conclude that B&V see that:

> The result is a projectivist account of colour: to see an external object as coloured is to project on to it a property that is in fact a property only of visual experience. It is an error theory of colour; to represent an object as coloured is to mispresent it. (p. 280).

Bigelow et al., (1990) dispute that the yellow after-image has the same property as a yellow object. They say that:

> Seeing a yellow after-image, that is, seeing it as a yellow after-image, does not involve representing something as having the property of being yellow. After-images are not represented in visual experience at all. (p. 281).

To support this suggestion they appeal to Peacocke's distinction between yellow and yellow'. They argue that:

> yellowness' , the sensational property of the visual experience, is not to be assumed to be the same property as yellowness, the quality attributed to the taxi cab. In fact, we have no reason to think that yellowness' is a colour at all. (p. 281).

I would not dispute the conclusion of Bigelow et al., (1990) that after-images don't have colour properties, and I would stress that AI's are physical mechanisms in the retina. I would also not agree with B&V's conclusion that the colour of the taxi cab is a property of part of the region of the visual field. To support these arguments I would refer back to my argument about after-images and topic-neutral accounts (Chapter 7.2 above). I argue that with a yellow AI something is going on just like what is going on when a yellow object is before one. An AI appears to be a physical property of retinal neural events, located either in the receptors for intense stimuli or in other neural entities in the retina for moderate stimuli (Virsu & Laurinen, 1977). This physical property can act together with an external stimulus to produce other coloured effects (Day & Webster, 1989; Anstis et al., 1978). Thus an AI can be given a physicalist explanation as it is a physical effect induced directly by an external stimulus but which occurs after the external stimulus ceases (Day & Webster, 1989). Bigelow et al., (1990) have also argued that the 'physical effect' is like what goes on in one when you see something which appears to have a colour, i.e. the physical effect has a colour. But that does not mean that the 'physical effect' counts as seeing a thing which seems to have a colour property. This is basically my topic neutral account.

12.3.3 Boghossian and Velleman and physical theories of colour.

Boghossian and Velleman (1991) (B&V 1991) discuss the issue of colour realism in the form of colours of material objects that are microphysical properties of their surfaces. They argue that the claim that colour is a microphysical property can express either of two very different theses. One, they describe as the identity-physicalism (IP) view which says that colour is one and the same property as a microphysical configuration. The other is what they call realization-physicalism (RP), which says that the microphysical configuration is merely a way of being coloured. They argue that the difference between these two views is analogous to that between type-physicalism and functionalist materialism in the philosophy of mind. Just as physicalism says that pain is the same state as excited neurones, IP says colour is the same state as excited neurones; and as functionalism says that pain is the higher-level state of occupying some state that plays a particular role, then RP does the same with colour. Both views argue that colour is a neural state but only IP asserts an identity.

B&V (1991) also make a two by two set of distinctions. They argue that physicalists can also be distinguished by their views about the propositional content of color experience. First, a physicalist may take a Fregean view of the visual representation of colour. They say that:

> according to that view, the experience of seeing something as red has content by virtue of the subject's relation to a proposition containing a concept, characterization, or (as we have put it) mode of presentation that is uniquely satisfied by instances of red. The property itself is not an element of the propositional content, as the Fregean conceives it; rather, it is represented by an element of the content, namely, a characterization. (p. 110).

As an example of their Fregean theory approach, B&V (1991) suppose that the mental correlate of a colour category was an introspectible sensation or quale, then:

> the resources for a Fregean theory become available. The content of a visual experience can then be imagined to invoke the accompanying sensation and hence to characterize its object under the description ' having the property that is this sensation's normal or predominant cause'. (p. 114).

The second view that B&V (1991) propose about how a physicalist views colour is that:

> a physicalist might take a completely different view of how colour is visually represented, a view that we shall call Russellian. According to that view, the experience of seeing something as red has that content by virtue of the subject's relation to a proposition containing the property red.....the property itself, not a conception, characterization, or presentation of it. (p.110).

As an example of a Russellian view, they quote Armstrong (Armstrong & Malcolm, 1984):

> A perception of something green will involve a green-sensitive element, that is to say, something which in a normal environment, is characteristically brought into existence by green things, and which permits the perceiver, if he should so desire, to discriminate by his behaviour the objects from things which are not green. (p. 172).

They also cite Jackson & Pargetter (1987) as an example of a Russellian approach when they say " redness is the property of objects which causes objects to look red " (p. 129).

B&V (1991) develop a number of proposals for ways in which visual experience might represent microphysically constituted colour properties. These proposals are all considered in the context of what B&V state as the naive objection to physicalism:

The microphysical properties of an object are invisible and hence cannot be what is represented when an object looks coloured. One can tell an object's colour just by looking at it, but one cannot tell anything about its molecular structure... nor, indeed, that it has such a structure... without the aid of instruments or experimentation. How can colours, which are visible, be microphysical properties, which are not? (p. 108).

Although B&V go on to discuss this objection, it really represents their central epistemological intuition that they rely on; that we can, by introspection alone, know which properties our colour experiences represent. This is essentially a revelation account of colour which I will examine in detail later in Chapter16.0

B&V examine these proposals about visual experience. They begin with a Humean proposal that colours are directly denoted by the subject's classificatory dispositions. In this situation, red has the indexical character " it's one of that kind ". The reference of " that kind" is determined by the subject's disposition, by experience, to group objects together with other objects. If the latter objects can constitute a kind by possessing a common property, then that property could easily be microphysical or realized microphysically. They argue against this proposal by the fact that the objects would only have this property in common. But this would mean a requirement to have an antecedent capacity to represent colour, which they argue would render the specification of the kind superfluous.

They also consider what they call an information-theoretic approach. They consider that the mental correlate of a colour category might be an introspectible sensation or quale. They then say that such an account of colour can be adopted by both IP and RP versions of physicalism, in that:

> an identity-physicalist can say that red is the property referred to within the proposed characterization.....the property that tends to cause the accompanying sensation. A realization-physicalist can say that red is the higher-order property expressed by the entire characterization—the property of having the property that tends to cause the sensation. (p. 114).

However, they conclude that these proposals:

are uniformally unsuccessful in showing that visual experience might represent microphysical or microphysical realized colors. Each of them fails to satisfy one of two fundamental requirements for an adequate theory of color vision. (p.116).

First, they say that a theory of colour must respect the epistemology of colour experience, i.e. it must be compatible with one's knowing what one knows about colour properties simply on the basis of seeing them. As I said earlier, this is a revelation account of colour and it will be addressed in more detail in Chapter 16.0. Second, a theory of colour must respect the phenomenology of colour experience, e.g. it must be compatible with what it's like to see the world as coloured. In their opinion " no physicalist theory can meet this phenomenological restraint while meeting those imposed by epistemology of color as well. (p. 116).

However, B&V's arguments really boil down to the intrinsic and revelation arguments cited above, e. g. :

> mere reflection on color experience provides all the support that might ever be needed for all the knowledge cited above. That is, you need only reflect on the experiences of seeing things as red and as orange in order to know that they are two distinct, incompatible, but rather similar determinates of a single determinable property; you need only reflect on particular experiences in order to tell which of these properties they represent; and there are no possible circumstances under which more evidence would be needed. (p.117).

B&V (1991) go on to argue that physicalist theories don't support these as necessary experiences so they make the knowledge of colours to be contingent and:

> then your knowledge of these matters would be hostage to future empirical discoveries. You would have to consider the possibility of obtaining evidence that red and orange are in fact the same property or, conversely, that they aren't similar at all. (p. 117).

As Watkins (1997) points out B&V (1991) offer little support for their epistemological intuition and raises serious doubts about B&V's proposition that by introspection alone we know which properties our colour experiences represent.

B&V (1991) argue that only the Fregean, RP version gets the epistemology correct but it fails with the phenomenology since it:

> portrays visual experience not only as having introspectible qualities but also as alluding to them in its representational content. This version of the proposal implies that visual experience not only involves color sensations but is also about those sensations, in addition to color properties—which is clearly mistaken. (p. 131).

They argue that it is mistaken because " the content of visual experience alludes to colour qualia as properties distinct from the perceived colors of objects " (p.130), and this gets the phenomenology wrong. Thus no version of physicalism simultaneously meets both their requirements for epistemology and for phenomenology. I suggest that if the topic neutral approach can be made to work with our additional suggestions about metamers etc., then B&V's objections can be overcome, as they are based solely on their assumption about their intuition. It is important to note that B&V give no information of how their concept of projection might work. As Armstrong argues this notion of projection is simply a metaphor.

12.3.4 McGilvray on colour and projectivism

McGilvray (1983,1994) has taken up a position very much like that of B&V, in that he argues that colours are subjective mental processes and like Hardin (1988) he argues that they are also neural processes. He says that " color subjectivism is the view that they (colors) are located inside us: in the mind or the brain " (p.197). Like both B&V and Hardin, he argues that these subjective colours are projected out onto objects in the world. McGilvray (1994) spends a lot of time attacking what he calls the most sophisticated colour objectivism view, that of Hilbert (1987). He says that this view holds that:

a particular color is identical with an instance of a property of a surface of a physical object that visual scientists and colorimetry specialists call surface spectral reflectance (SSR). These properties are not type reducible to more basic physical properties, but are objective physical properties nervertheless. SSR's measure the percentage of light a surface reflects at each wavelength; for humans, the relevant values are between 400 and 700 nanometers. (McGilvray, 1994, p. 199).

McGilvray (1994) raises two major problems for SSR's. First is our old problem of the existence of metamers, (e.g. A large number of surfaces with very different SSRs will appear the same colour). I have already argued that metamers don't necessarily present a problem for surface reflectances like SSRs, because of the broad tuning of natural objects (Maloney, 1986). Thus, vision could have evolved to detect SSRs. I think this partly true, but the theory I advocate in PE / W is more extensive since it covers all the mechanisms of Nassau (1983), which SSR theory does not, such as what Nassau describes as Geometrical and Physical Optics, e.g. his items 12 to 15 in Table 1.1. Second, this problem is what McGilvray calls the order problem. The order problem, according to McGilvray, is that colours are intrinsically ordered, but their ordering differs radically from any ordering found in SSRs. What McGilvray means by this is that there are no equivalents of unique hues and opponent colours in SSRs. He says:

> There is no 'natural' ordering of SSRs that looks at all like the ordering of colors... no 'unique SSRs, 'opponent'ones, or 'saturated ones.' (p. 203).

However, as I have stressed in this thesis, there is evidence that there are other relationships between colour processes and physical aspects of colour than just the opponent processes. That is, the central field of colour has more directions than the cardinal directions of opponent processes (D'Zumara, 1991). Thus the order problem does not carry so much critical weight to enable it to rule out identifying colour with physical processes. Given this evidence on metamers and opponent processes, it is difficult to support McGilvray's claim that;

we know what SSRs are, we know what colors are, and we know that many color experiences have the function of detecting color-related properties of external physical objects—that is, SSRs. But prima facie colors are not at all like SSRs. (p. 208).

As I emphasized earlier in Chapter 9, Armstrong (1993) has pointed out that no projectionist has given an adequate account of projection. McGilvray, unlike B&V and Hardin, spends some effort in discussing projectivism. McGilvray (1994) starts off addressing this issue by saying that:

> there are in fact two tasks for the subjectivist. One is to explain the phenomenological fact that we experience colored objects to be out there. These experienced colored objects do not have the appearances of colors, whatever they might be. The colors they have are honest colors, for these colors stand in relationships to each other in ways that, as Hardin points out, the neurophysiology of the human brain alone can explain. So the subjectivist must explain how to get genuine colors 'in the head' out there 'onto' external objects. I show that the only plausible way to do this is to make perceptual objects seen illusions created by our brains...projections of a neural conspiracy. The second task is to explain why these genuine colors seem to be continuing properties of things out there...even, for instance, when we are not looking at them. The only way to make colors largely abiding properties of things out there, I believe, is to tell a further story about *another form of projection* [my emphasis], driven by beliefs, that posit things seen. Only once both tasks are done, I suspect, can the philosophical thesis of color objectivism be put to rest. (p. 210).

This is a different form of projection from those put forward by B&V and Hardin, who only talk of one form of projection.

McGilvray (1994) presents a complex set of arguments to support his theory of two types of projection. For the first type of projection, he looks at the identity conditions for phenomenal objects. He argues that Hardin (1988) has produced good, but not quite sufficient, reasons to identify colours with neural events / states, which Hardin bases on the problems of opponency and order. McGilvray extends this identification to other features of colour and colour experiences and in particular to coloured phenomenal objects. He says that:

> phenomenal objects can be defined and individuated both experientially ('phenomenally') in terms of places in a visual discrimination space and neurally, in terms of instantiations of types of neural events found in certain neural complexes. (p. 213).

McGilvray asserts that both phenomenal and neural forms of individuation are independent of talk about the physical things and properties of physical things that (typically) cause phenomenal objects. He acknowledges, however, that:

> it might appear difficult to show that a phenomenal object individuated in terms of a place in discrimination space is independent of the things that typically cause it, because it might appear that a discrimination space is essentially tied to the things discriminated. The apparent difficulty arises from a methodological fact: the experiments that allow psychophysicists to construct a discrimination space for some modality that a particular individual has depend essentially on treating phenomenal objects as bearing information about things and properties 'out there'. (p. 213-214).

McGilvray (1994) has two sets of arguments to support this amazing assertion that phenomenal objects are independent of physical causes. First, he argues that he has shown that the properties of colours inside the head don't match up with or are ordered " in the ways that the properties of the physical things and properties they detect and gauge are " (p. 214). This is simply asserting again his arguments about metamers and opponent processes. Once again, I feel that the evidence about metamers in nature and the work showing multiple detection mechanisms as well as opponent mechanisms (D'Zmura (1991) don't support this conclusion. Second, McGilvray refers to the work of Clark (1993) who claims to show that discrimination spaces are independent of typical causes of sensory events. Clark (1993), in an excellent book, has given a detailed analysis of sensory qualities and how they can be put into quality spaces. Clark makes a distinction between a psychological colour solid (PCS) and a colour order system (COS). He asserts that a PCS is based on multidimensional scaling (MDS) techniques. As examples of PCS's, Clark cites the Munsell colour solid and a proximity analysis of colour by Shepard (1962). These are hardly convincing examples to support Clark's strong claims for PCS's and the MDS technique. Clark admits that the Munsell system predates MDS, but says that it was a kind of precursor to magnitude estimation systems. Clark says that a PCS is a quality space for colours, whereas a COS arranges a large number of colour patches in a three-dimensional array for some specific purpose. Clark (1993) does not give a specific example of a COS, but it is clear he means systems like the various CIE systems of colour. He argues that:

> if an order system is to represent colour quality space, distances must be monotonic over similarities. Pairs of colour samples that are equally distant should be equally similar. Few order systems attempt to meet this condition. (p. 121).

While it is true that few COS's meet this condition, Clark does not discuss those that attempt to meet it. There is the Optical Society of America uniform colour scale and two versions of CIE uniform colour scales (the 1976 CIELUV colour space and the 1976 CIELAB colour space). The CIELUV is used in television and video display industries, while the CIELAB is used widely in the paint, plastic and textile industries (Marcus, 1998).

Clark also argues that as well as distinguishing between a PCS and a COS, one should distinguish between a psychological colour solid and a wavelength mixture space. Clark points out that wavelength mixture space is derived from the effects of stimuli on three types of transducers, with each dimension representing the number of absorptions in one of the three classes of cones in the retina. He says that:

> A point in that space is an equivalence class with respect to those physical effects on transducers that bear information used in subsequent discriminations. (p. 124).

Despite this clear claim for the effects of physical stimuli, Clark wants to argue that a PCS quality space is independent of stimuli. He says that:

> It seems clear that one cannot define a 'place' in the quality space in terms of stimulus coordinates, since those stimulus coordinates differ among different people, and the coordinates of stimuli needed to present the same quale to a person change over time. (p.170).

It would seem, however, that both a PCS and a COS would suffer the same fate if Clark's arguments are valid. As I mentioned earlier, Clark bases his arguments largely on opponent processing details and metamers, which he claims have no counterpart in physical measures. For example, he points out that unique hues have no exact wavelength component. He quotes some data from Hurvich (1981) showing that for 50 individuals the wavelength setting for unique green had an average of 503 nm, but the settings ranged as much as 15nm on either side of the mode. It is true that such observations present a distinct limitation to both COS and PCS spaces in relation to physical variables. In Chapter 14.0 I will look at evidence against the problem of this range of settings of unique hues. However, the 1931 CIE space is never claimed to identify a particular colour. A given setting will not produce the same colour experience to every person. The important point is that these measures will allow different laboratories to produce identical colours using the coordinates without any observer being present. Individual observers will see different colours, but the colours produced by different laboratories will match for each observer. I would want to argue that the system is giving a form of measurement of colour based on three stimuli. It is admitted that the measures are based on the mean of the standard observer (i.e. the groups of observers tested by Wright and by Guild) and on restricted viewing conditions such as a 2° visual field. But it is still a form of measurement based on the wavelengths of the three primaries and in my view makes colour a primary property, given Campbell's (1972) arguments about measurement and secondary qualities.

Clark (1996), in a later paper, argues that his subjective view about colour is a form of reductionism. He says that:

> if you think that humans can explain some of the phenomena of color vision, and you agree that the physics of the phenomena outside the skin are not likely to do the job, then you have little option but to agree that

the explanation of these sensory capacities will be physiological. And so you are committed a version of reductionism, Welcome to the club. (p. S146).

Clark (1996) says he is detailing the structure of quality space, defining places within it, then providing a neurophysiological interpretation for some of its axes. Clark (1996) like Hardin (1988) wants to argue that colours are illusory. He says that:

> subjectivists claim that all colours are, in this sense, false colors. Color similarities may not represent any identity of physical properties other than the propensity of disparate classes of objects to affect our receptors in the same way. In that sense colors are 'illusory' (Hardin, 1990b, 1992)......Illusions can be useful. The sense in which chromatic experiences are illusory in no way precludes their having a useful biological role.. (p. S 148).

Clark (1993), unlike Hardin, does not talk about projection of subjective colour onto objects, but McGilvray (1994) feels that Clark's arguments support such projections.

McGilvray (1994) presents, what is to me, an amazing set of arguments for his other form of projection. McGilvray bases his arguments around a theoretical entity he calls a posit. I can only explain this concept and its relation to projection by extensive quotations from McGilvray. McGilvray says that:

> Because I propose an unusual position, that appearance of colors outside ourselves is just that (a mere appearance or illusion) and that our sensory systems construct these illusions (or perceptual objects). (p 225).

He goes on to say::

> To deal with these colored continuants, the projective subjectivist must introduce yet another class of non-existent objects......objects that can be described as colored and as outside, yet where their colors persist (even when no organism is looking at them). These too must be manufactured, although not in the same way. They are the products of a belief-based

process of construction and projection. Call it 'positing'. The concept of a posit is essentially that of a theoretical entity. A creature that has a certain kind of theory of its world posits certain kinds of entities......we obviously need colored continuants to explain perceptual beliefs of language-using humans, and so we can say that humans posit such entities. (p. 229-230).

This is indeed a complex theory of projection as shown when McGilvray goes on to say:

> To shorten a very long story, I suggest that common sense objects be thought of as bastardized entities that combine both perceptual objects (already 'outside', due to our sensory machinery) and posits of our beliefs (including expectations and memories).......These projected, posited, bastardized objects seem to be legitimate... even more legitimate than external physical objects and phenomenal objects. (p. 233).

He then says:

> To fill out projective subjectivism, I have to say how these objects come by their colors and whether they exist. The projective subjectivist must hold that if they are external (as most of them are) they cannot really be colored. And if they are both colored and external, they do not exist. (p. 233).

I think that this theory makes a simple realist theory of colour to be even more appealing compared with the postulation of two projection mechanisms projecting two sorts of non-existent entities.

As Armstrong (1993) has stressed, most projectionists have not explained how projection can work so accurately. There have been other proponents of projection. For example, Baldwin (1992) has proposed a projective theory of sensory content. Baldwin has based his theory largely on the work of O'Shaughnessy (1980). However, neither has given a detailed analysis like that of McGilvray. They both rely on colour as an example of sensation, which they argue is not in the world and thus needs to be projected. Baldwin (1992) has an amusing quotation from Broad (1923) which I think makes a strong point about all types of projection. Broad says of projection that:

> Now this muddled mixture of theories is not consistent with itself or with the facts. It is inconsistent with itself for the following reason. When I look at a penny, the brown colour that I see is seen spread out over the round contour... we are asked to believe that there is browness without shape 'in me', and round shape without colour out where the penny is, and yet in some mysterious way, the shapeless browness 'in me' is projected into the round contour of the penny 'out there'. If this not be nonsense I do not know what nonsense is (p.273-274).

Although Broad's comments support the mysteriousness of projection as a mechanism, he made these comments from an unusual position. He had proposed the concept of sensa, which he claimed had both colour and shape built into it. Thus colour, according to him, could not be browness without shape. However, his concept of sensa is difficult to understand. For example, what is the relation of a sensum to a sensation? Broad (1923) says that:

> A sensation, on our view, is a complex in which an objective factor (the sensum) and a subjective factor (the act of sensing) can be distinguished. (p. 516).

He appears to argue that sensa are between sensations and physical objects. He says that:

> It seems necessary to hold that the sensation and the sensum are not identical; that the sensum is an objective constituent of the sensation; and that there is another constituent which is not objective and may be called 'the act of sensing'. (p. 257).

This view is like the sense datum theory which contradicts physicalism. I find this overall position of Broad to be difficult to understand, however, I will not proceed with it as it is not relevant to my general argument.

The issue of projectivism is also discussed in a recent book on colour by Stroud (2000). This is a most unusual book on colour. His topic is subjectivism and the metaphysics of colour. He appears to agree that science claims that colour is not in the world. He puts forward two subjective positions. The first is that colour sensations are projected onto objects. He does not explain projection, but eventually decides against this position. He then embraces a dispositional account, but he is not entirely happy with this. Instead, he presents a rather odd intentional account of colour in terms of belief, but still with subjective overtones. This is, indeed, an odd book. In the book, Stroud cites people such as Hardin, Hilbert; Jackson and Pargetter and Maund in references and some footnotes. However, he never gives any analysis of their theories on colour. It is difficult to comprehend how you can discuss colour without at least discussing these theories. In fact, most of the modern literature is ignored. Perhaps, I have been a little hard on Stroud in this regard, because he specifically states that modern theories of colour are such that:

> much of it is devoted to attacking or defending one or another philosophical theory of the nature of colour. My interest is more in the metaphysical project which such theories are meant to advance. The issues I concentrate on are crucial to the success of such theories, but I do not always pursue them by taking up in detail this or that person's theory and certainly not trying to cover them all. (p. Xiii).

I find it difficult to accept this position when Stroud (2000) claims that:

> The whole rich complex of all our colour beliefs and perceptions would have to be fitted into and explained on a world described by nothing more than the statements and laws of physical science. For one perfectly straightforward reason, it is clearly impossible to do that. We have conceded that no colour facts are to be found in a purely physical world; the physical vocabulary does not contain the resources for saying anything about the colours of things. But the physical vocabulary does nor contain resources for saying anything about anyone's perceiving or believing or thinking

> about anything either. No psychological facts are to be found in a purely physical world. (p. 77).

I give this long quotation as I find it hard to see how Stroud can support such a strong subjective approach, given my physicalist leanings. Stroud's attack on physicalism has been described by Campbell (2001) as:

> This is a somswhat dispiriting book. It mounts an extensive, elaborate, even laboured case for negative thesis, that the metaphysical project of reductive naturalism, or physicalism, is doomed to failure. (p. 443).

Stroud argues that the physicalist holds that all the facts are physical facts. As Campbell (2001) points out this is a suicidal position for a physicalist to adopt, since there are many facts such as dreaming, believing in God etc, that cannot be expressed in a physical vocabulary. Instead, physicalists should argue that there are no entities, and no forces, beyond those recognized in best current physics.

Overall, these general positions on projection seem to support Armstrong's (1993) claim that projectionists have never explained how projection can be so accurate unless it is colour out there which is producing the precision. Overall, I regard the concept of projection to have too many problems to explain colour.

12.3.5 Westphal on Colour

In two important books, Westphal (1987,1991) analyses colour in the context of Wittgenstein's Remarks on Colour (1978). Westphal launches a severe attack on the physicalism of colour and, in particular, on Armstrong's physicalist theory. As Hardin says:

> There is much else to be found in this small book, such as a devastating attack on Armstrong's physicalist theory of colours. (Hardin, 1989, p. 147).

Westphal claims to have a full refutation of physicalism per se. He is one of the few people in addressing what Gold calls the "central problem of colour", (i.e.

whether colour is in the world or in the mind), to look at the issue in terms of a valid form of reductionism. He says:

> It is a necessary condition for reduction in the Tarski and Woodger's sense that statements which are true in the reduced theory should be preserved in the reducing theory. Armstrong does not say what he understands by reduction but I shall assume that if I can show that this condition is not satisfied, the reduction must fail. The absence of biconditionals relating each primitive predicate of the reduced theory to some, possibly complex predicate of the reducing theory means that the physical theory does not even interpret the psychological theory in Tarski and Woodger's sense. Without fixing the sense of 'reduces', it is hardly worth discussing the reducibility of colour theory to physics, or to anything else. (Westphal, 1991, p. 90).

Westphal concentrates on the replacement of psychological predicates by psychophysical predicates as the first stage in reducing colour to physical predicates. He says:

> If the reduction fails here, it is irrelevant whether another reduction could be performed on the psychophysical terms. (Westphal, 1991, p. 91).

It is interesting that all the major proponents of a physical account of colour that I have examined don't give any account of how they would reduce colour theory to a physical theory. (Hilbert,1987; Jackson, 1996; Tye, 2000; Campbell, 1993; Ross, 2000; Matthen, 1999). Yet this would seem to be an important component of such a move. Westphal looks at a number of features of the psychology of colour:

(1): hue and dominant wavelength: this is the problem of saturation of colour. He says:

> We know that a colour (strictly, perhaps, an absolutely determinate hue or colloquially a shade of colour) can be saturated or unsaturated. But it is some kind of nonsense—a category mistake—to say

> that a light emission of such and such wavelength is saturated or unsaturated. (Westphal, 1991, p.91).

Westphal argues that the physicalist requires not only a reduction of colour words like 'red' and 'green', but the additional reduction of saturation to 'colorimetric purity' and brightness to 'luminance'. The colorimetric purity of a sample is the ratio of the amount of a spectrum component to the sum of this component and the daylight component (or white). Also the term 'dominant wavelength' is important in this context. It is the wavelength of that part of the spectrum required to mix with daylight or white to produce the colour. Westphal (1991) points out that there is a variation of hue with variation in saturation (the Abney (1910) effect). For example, the addition of white to blue makes the colour not only whiter, but changes the colour from blue to mauve, however the dominant wavelength does not change, and thus the mauve we see corresponds to light emissions whose dominant wavelength still lies in the blue. As Westphal argues that:

> Substituting 'dominant wavelength' for 'hue' and 'colormetric purity' for 'saturation' we get the statement that there is a variation in dominant wavelength with colometric purity. This statement is either false or nonsensical. (p. 92).

Thus the reduction does not appear to work. This effect occurs across the spectrum. (Figure 17).

(2): adaptation and colour constancy: Westphal (1991) argues that these concepts are difficult for a reduction. The colour of the light reflected into the eye will vary enormously through the day, but objects do not change colour, nor do we see a change. Westphal says this is due to adaptation to the colour of the illumination. Thus the reducing theory reports a change in the colours of objects (i.e. wavelength) which the reduced theory denies.

(3): hue and brightness: Westphal (1991) points out brightness varies with hue with yellows and greens showing the greatest brightness. However, the reducing theory has the colours at the same energy level.

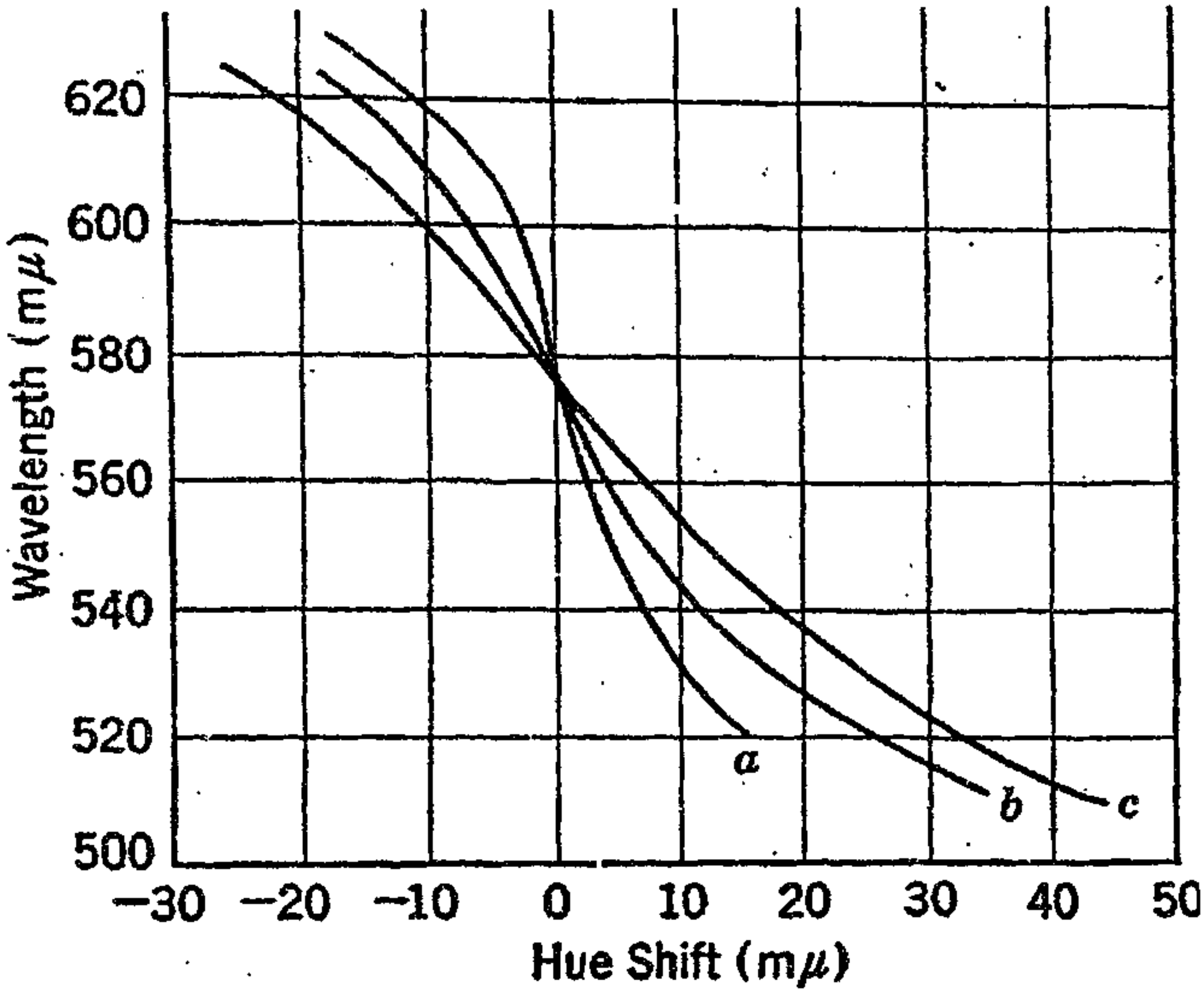


Figure 17: Graph showing the shift in hue, as measured in millimicrons, when the amount of white light is added to the colours of the spectrum is (a) 43%,(b) 21.5%, (c) 15%. Above 577 mμ the hue tends to shift away from the red end of the spectrum and below this point the hue shifts toward the red end. (from Evans,1948)

(4): Unitary hues: Westphal points out that there are 4 unitary hues, but the positions of these hues cannot be explained by the physics of the stimulus. Instead they are explained by post-retinal coding (i. e. opponent processes). Westphal asks " what predicate in the reducing theory will 'unitary' reduce? " (p. 94). Thus " we have a clear truth in the reduced theory...which is not preserved in the reducing theory, and cannot even be stated in it" (Westphal, 1991, p. 94).

(5): Primaries: Westphal (1991) says that the same problem arises with the primaries of additive or light mixing and the primaries of subtractive or pigment mixing. The physical theory needs to be able to identify what a primary is in physical terms.

(6): Rate of change in the spectrum: Westphal points out that hue changes quickly in the middle of the spectrum, but slowly at the ends of the spectrum. Westphal asks what will be the corresponding statement in the physical reducing theory? He suggests that we would have the odd position that dominant wavelength and ultimately wavelength of light emission changes slowly in the extremes and quickly in the centre. This would appear to be quite anomolous.

(7): Metamerism: Westphal points out that a physicalist theory can't reduce the colours of metamers to wavelength as they differ for the same colour in the reduced theory.

(8): Grassman's third law: Westphal argues that Grassman's third law is difficult for the reducing theory. This law states that colours that are the same colour give identical mixed colours if each is mixed with the same colour. This means that metamers will show this effect even if their wavelengths differ, thus it is difficult to have a reduction.

(9): There is another problem for a reducing theory that Westphal does not mention. This is the Bezold-Brücke effect, in which there is a change in hue with a variation in intensity or brightness .(Purdy, 1931,1937).(Figure 18).

(10): Another problem for a reducing theory is the change of hue with the size of a stimulus e.g. " Isolated objects of the very smallest angular sizes produce no hue response" (Burnham et al., 1963, p.62).

12.3.5.1 Replies to Westphal's Arguments

It is clear that Westphal (1991) has raised some important issues for any physicalist theory of colour. It is clear that there are problems in generating bridging biconditionals to cover the above problems. However, if our arguments about metamers are accepted, i.e. metamers don't occur in nature, then items 7 and 8 are perhaps not serious. This would appear to allow a general reduction of colour to wavelength. The other points, however, are still difficult for a physicalist account of reduction, but if we look closely at the visual literature we might be able to overcome the problems by relating them to physical mechanisms in the visual system. It should be stressed that wavelength realism asserts that colour is determined both by physical properties out in the world and by neurophysiological mechanisms, as we emphasized in chapter 7. This is an approach similar to that of Jackson (1996) and Hilbert (1987) in that colour is an anthropocentric property. It is based on an observer-independent property, but which observer-independent physical properties they are is, in part, a human-observer-relative matter.

If we look at Westphal's first point about colour changes with variation in saturation. Westphal emphasizes that we have a change in dominant wavelength with colometric purity. However, if we look at the original data of Abney (1910), we see some interesting observations which Westphal does not mention. Abney reported that wavelength 577.2 nm did not show this change with increase in the level of white. He puts forward the hypothesis that this colour has the same proportion of red and green as white light. Thus the addition of white light would make no difference to the colour. This assumes that blue light in white has little or no effect. Abney then shows that this change in the proportions of red and green leads to the changes in colour. Those colours below 577.2 shift up towards 577.2 and those above (e.g. orange and red) shift down in colour towards yellow, due to this change in the proportions of red and green in the mixed stimuli. These calculations would seem to suggest that there has been an underlying wavelength change, thus the dominant wavelength does not remain constant and so a wavelength theory would not have the difficulty in giving an explanation as was suggested by Westphal.

It should be noted that Purdy (1931) disagrees with Abney and reports that the small quantity of blue should not be ignored and claims that the introduction of white corresponds to an enhancement of the red and blue components rather than the red and green proposed by Abney. No matter which hypothesis is true, it indicates either way that the dominant wavelength is modifided by the addition of white.

The second point of Westphal concerns the effects of adaptation and colour constancy. Both of these raise serious issues for wavelength realism as they imply that colour can either change without a change in wavelength (adaptation) or not change with a change in wavelength (colour constancy). Forsyth (1990) describes colour constancy as " a remarkable human skill: people are able to describe the colour of an object in a way that is largely independent of the lighting in which they find it " (p. 201). However, we have seen earlier that both adaptation and colour constancy are not so important under the natural conditions under which our colour system evolved (Chapter 6). A wavelength account still appears possible as objects retain their daylight colour as long as their dominant wavelength is present, even in very small amounts. Helson (1938) points out that:

> objects regain their daylight appearance......with as little as four-tenths of one percent non-homogeneous light " added to homogeneous coloured lights (p. 466).

The third point of Westphal is that brightness varies with hue with yellows and greens showing the greatest brightness. It is clear that wavelength theory does not readily explain these observations. It needs some additions based on neural mechanisms to give a reductive account of these effects. It is clear that the visual system is more sensitive in the region around 550 nm (Evans, 1948; Hurvich, 1981), although the mechanism for this sensitivity is not known. However, Kaiser & Boynton (1996) point put that this sensitivity is to the region of the spectrum where the radiation reaching the earth from the sun is the most plentiful. Hence, it is not a surprise that we have evolved extra sensitivity at this region. That is, an anthropocentric account is needed for wavelength theory to account for these data.

The fourth point involves the four unitary or unique hues. Westphal argues that there is general agreement in colour science that the explanation of unitary hues lies in post-retinal coding. The evidence cited earlier (chapter 4) indicates that not all of visual science is happy with opponent processes and unique hues, even if they don't have a complete explanation. That is, both the reduced and the reducing theory have problems with this issue. I present some very recent evidence in Chapter 14.0 about unique hues, which suggests that there is not general agreement about the relationship of unique hues to opponent processes.

The fifth point is whether wavelength theory can account for both the primaries of additive light mixing and the primaries of subtractive or pigment mixing. Westphal argues that the reducing theory must be able to provide a statement of what a primary is, because, in the case of additive primaries, they have no physical distinction in terms of electromagnetic radiation. It is clear that additive primaries can be based on a large range of primaries to match any colour. However, if our argument about metamers is accepted, then in nature we won't find such a range of primaries, instead natural colours appear to be based on broad peaks in the spectrum. In the case of subtractive primaries, we have a situation that is more congenial to wavelength explanations. The subjective primaries (yellow, magneta, and cyan) are the complementaries of the additive primaries (Falk et al., 1986). They occur when blue, green, and red are absorbed from white light as they are based on absorption of certain wavelengths and the transmission of the remainder. Once again wavelength theory needs expanding to include anthropocentric factors and other physical factors. In the case of subtractive primaries, some physical account must be provided using Nassua's electron explanation of pigments, which we have suggested as being related to wavelength explanations.

Westphal (1987) argues that:

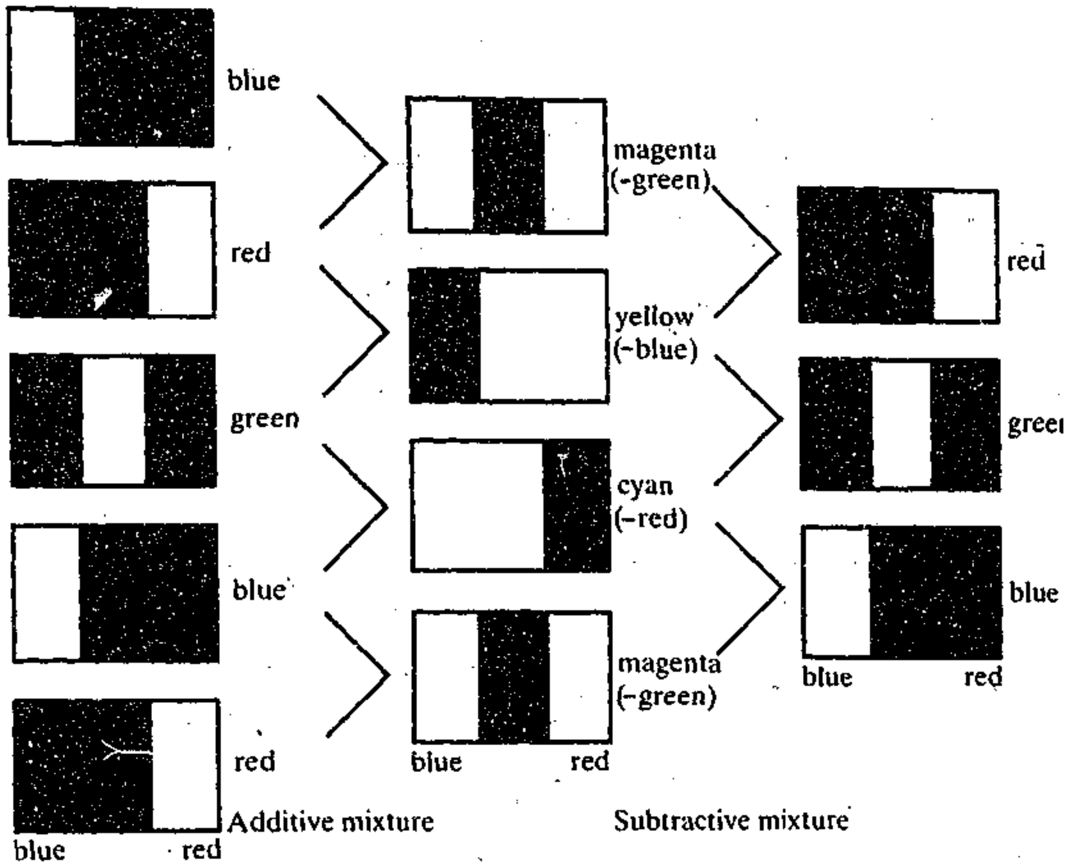
> my own view is that there is a ' general formula' of a certain kind under which the same colours, correlated with different frequencies, fall; but it is a formula concerned with light or illumination as this is perceived, and the darkening of the light by objects, which produces edges. It is not a

complicated formula, and it has only a complicated and peripheral relationship to the spectral composition of the light. On this view, the theory of colour will not reduce to physics, not only because the idiosyncratic nature of colour prevents it, but because the received physical account is wrong. (p. 101).

This approach is based on the conception of colour put forward by Wilson and Brockelbank (1962). They argued that the significant property for colour perception is not the colour or spectral composition of the light they reflect, but rather the colour of the light they don't reflect, i.e. the colour of the light they darken or absorb. Thus, a green object in this scheme is an object which refuses to reflect a significant proportion of red light relative to lights of the other colours, including green.

This is an interesting theory, which Westphal summarizes in a diagram he modified from Wright (1961-2). (Figure 19). The main modification was to change the abscissa from a wavelength scale to a spectrum scale from blue to red. (Figure 19). In this diagram Westphal tries to represent the facts of colour mixing, for both additive and subtractive functions, with filters of different primary colours. The additive primaries are shown on the left of the figure and subtractive primaries on the right. The coloured filters displayed are ideal in the sense that the blue filter transmits only blue light and hence the transmittance curve is vertical. In the additive part of the diagram, the rule is that light prevails or is dominant, so that light + black = light. Thus for red and green, we add the lights or the white parts of the diagram, and leave over in darkness or black only the blue part of the spectrum, so the result is negative blue or yellow. For the subtractive mixing, dark prevails or is dominant, so that light + dark = dark or in the diagram white + black= black. Thus from yellow (-blue) and cyan blue (-red) we get green. Note that from additive mixing, yellow and blue would only give us white or zero spectrum.

Westphal argues that the Wilson and Brockelbank theory would not serve as a physicalist reduction. Yet it does seem to fit Nassau's electron theory in the case of subtractive mixing. For this reason, I have placed Westphal in the realist /



PRINCIPLES OF LIGHT AND PIGMENT MIXING

Figure 19: Schematic diagram showing Westphal's idea that the basis of colour is not the light that objects reflect, but rather the light they don't reflect. The figure shows this concept in relation to both additive and subtractive mixing. (from Westphal,1987).

materialist cell of Table 3 with a question mark alongside his name. That is, colours of objects are determined by the energy of photons which cause absorptions of certain wavelengths and the reflection of others. These processes are clearly physical mechanisms and could be the basis of wavelength physicalist reductions. Using Westphal's own approach, a wavelength account can be given of the primaries for both subtractive and additive mixing, given that metamers don't occur in nature. There remains a difficulty for additive mixing in that an infinite set of three wavelengths (or metamers) can compose the three primaries that can match any colour. This is obviously dependent on the fact that there are 3 types of cone. But if in nature there are no metamers and colours in nature are generally composed of one peak in wavelength, then such complex mixing functions will not occur in nature. Thus wavelength theory can account for additive and subtractive primaries with wavelength and / or energy mechanisms. It is clear that while wavelength theory relates wavelength to hue it needs expanding with other physical mechanisms to provide bridging laws relating to the other complexities of colour vision. Perhaps, this expansion might take the form of the co-evolution of the reduced and the reducing theory, in the manner proposed by P.S. Churchland (1988) for the mind-body problem. That is, the reduced theory might be expanded to include microphysical mechanisms to overcome the bridging problems. This general issue will be addressed in more detail later.

The sixth point is that hue changes faster as a function of wavelength in the middle of the spectrum. These observations present considerable problems for our wavelength theory, as opponent processes have been strongly evoked in explanations of this effect (Kaiser & Boynton, 1996, Chapter 8). Wright (1946) published the first data on this issue (Figure 20). Two features of human vision are clearly seen in these data. First, human colour vision is extremely sensitive with ' just noticeable differences' (JND's) of around 1-2mμ over a large proportion of the spectrum. While the elevation of JND's is seen at each end of the spectrum, most of the JND's lie between 1 and 3 mμ. Thus some explanation is needed for the very low and very high wavelength regions. Second, there is great variability in the responses of the 5 subjects. This is particularly evident in the low wavelength region, although the high wavelength region shows considerable

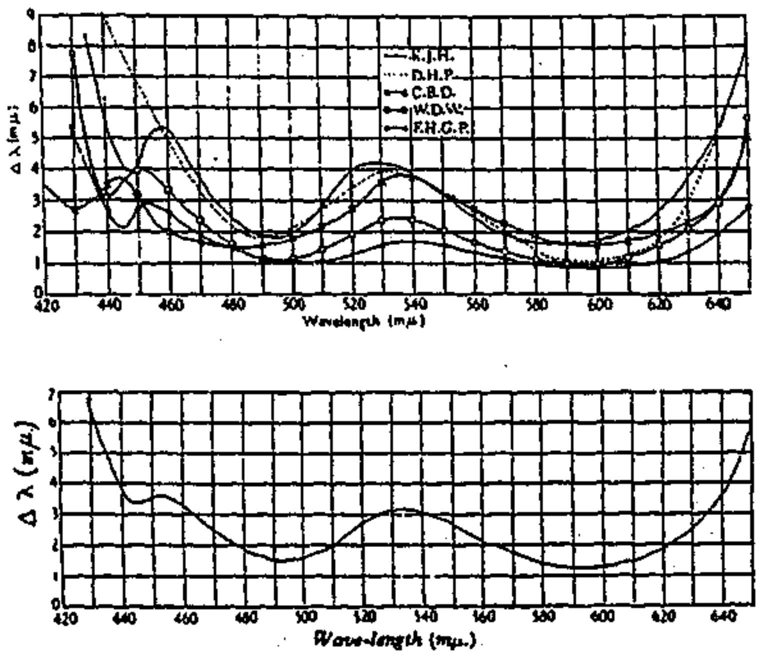


Figure 20:Wavelength discrimination functions obtained by Wright. The method of adjustment was used and the intensity of the Spectrum was about 70 trolands but was somewhat less in the short wavelengths. The bottom curve, which is the mean of the five observers (Upper curve) ,has been frequently reproduced as a typical wavelength discrimination function. (from Kaiser & Boynton,1996).

variation. It is argued that the low wavelength region might be produced by small field tritanopia (Kaiser & Boynton, 1996, p 344). That is, it might be produced by the scarcity of S cones in the fovea. Kaiser and Boynton (1996) point out that the short wave segment of the average curves in the literature are so widely discrepant that they are of dubious value, although they all show an increase in JND's. On this basis, wavelength explanations could cope with this variation by co-evolution of mechanisms in this region. There does not seem to be an explanation of the increase in JND's at the high wavelength end, but this does not appear to be something that a wavelength reduction could not handle. Even if it is an ad-hoc account.

The ninth point has not been raised by Westphal. It is that colour perception changes with changes in stimulus intensity. This is known as the Bezold- Brücke effect after its discoverers. Helmholtz (1924) noted that as intensity of spectral colours is made very great they undergo a change of hue. The colours corresponding to the longer wave lengths (red and orange) tending to change towards yellow. Those corresponding to shorter wavelengths (green, blue-green and violet) tending to change towards blue. Helmholtz also pointed out that at the same time the colours become more whitish (less saturated), and eventually when intensity becomes sufficently great, the entire spectrum becomes colourless. Decreases in intensity also produce changes in hue. Longer wavelengths tend to change towards red, the opposite to increased intensity change. Shorter wavelengths tend towards green, also the opposite direction to an increase. Purdy (1931) was the first to make a careful quantitative study and to determine the changes. (Figure 18 and Table II). It should be noted that this figure shows three invariable points in the spectral hues where hue does not change with intensity. In considering this figure, one should note that the contours represent changes with decreases in intensity. Thus with red and orange wavelengths, the decrease tends to a change towards red. Consequently, the slope of the contours is in the opposite direction towards green. In the YG region, the change is towards green, so the slope veers towards green to keep hue constant.

The invariable points have been correlated by Hurvich (1981) with unique hues without any evidence presented. However, Boynton & Gordon (1965) found

Bezold-Brücke Phenomenon

The table shows the increment or decrement in wave-length (millimicrons) that is required to maintain constancy of hue in the face of the intensitive decrement (photons) listed at the top of each column.

Wave-length of brighter stimulus	Intensitive decrement in photons					
	2000 to 400	2000 to 100	1000 to 100	400 to 100	400 to 20	100 to 10
660	−23	−34	−31	−15	—	—
650	−19	−26	−26	−13	−24	—
625	−5	−11	−14	−8	−12	−11
600	−3	−6	−6	−4	−7	−4
575	−1	−2	0	+1	−1	−1
550	+7	+8	+5	+5	+6	+2
525	+11	+21	+20	+8	+18	+4
505	+2	−2	−2	+3	0	+4
500	−2	−4	−4	0	−3	0
490	−2	−3	−3	−1	−3	−2
475	+2	0	0	+1	−2	0
460	+2	+3	+5	+1	+2	+6

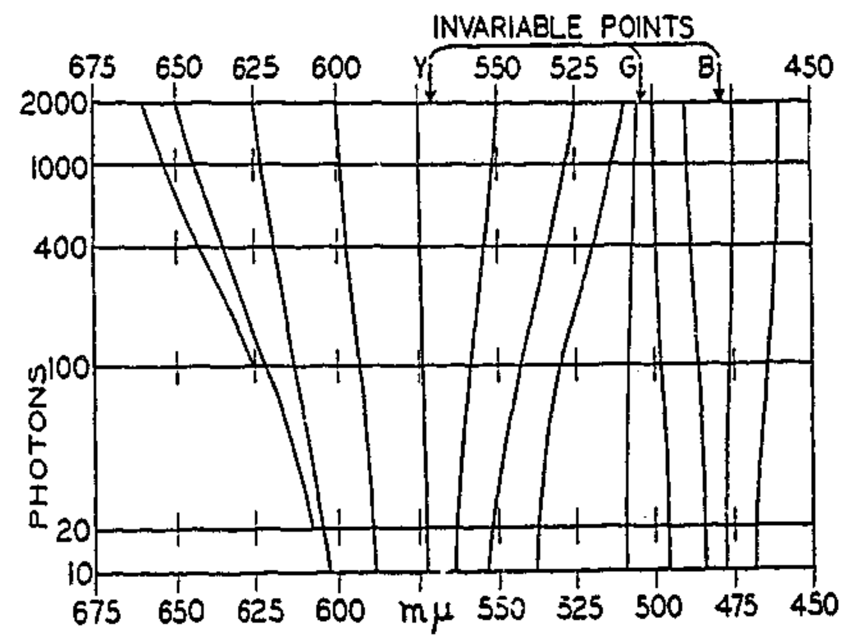


Figure 18 and TableII: Bezold-Brücke phenomenon and contours for constant hue. The figure shows contours for constant hue plotted against stimulus-intensity (photons) and wavelength (millimicrons). The contours converge upon or diverge from three spectral invariable points (three arrows). (from Purdy,1937).

that unique yellow (579 nm) was different from their invariable yellow (570 nm). Purdy (1931) also found a similar discrepancy (576 v 571). Purdy also found a discrepancy between unique and invariant red. Vos (1986) has presented evidence that unique and invariant hues are not coupled. He claims that the Bezold-Brücke effect occurs at the receptors rather than by opponent processes and can be accounted for if the ratio of receptors in the retina is set at N_s: N_m: N_l=1:10:20. He argues that " That means that unique hues are essentially different from invariant hues " (Voss, 1986, p341). In a recent study (Pridmore (1999), has shown that unique hues are not invariant, and, remarkably, has shown invariant properties for some binary hues. This suggests that wavelength theory could be expanded and the co-evolution of the reducing and the reduced theories to account for the Bezold-Brücke effect and the disappearance of colour at high intensity by incorporating receptor factors.

Overall, I would like to claim that Westphal's arguments against the reduction of colour are not as devastating as Hardin (1989) claims. The photon energy / wavelength reduction will require, however, some future developments to explain completely some of the issues raised by Westphal.

CHAPTER 13.0

13.1 Consciousness and Qualia: Their Nature and the Relationship with Colour

Ned Block (1995) has put the problem of qualia and consciousness quite dramatically. He says:

> The greatest chasm in the philosophy of mind... maybe even all philosophy..... divides two perspectives on consciousness. The two perspectives differ on whether there is anything in the phenomenal character of conscious experience that goes beyond the intentional, the cognitive and the functional. A convenient terminological handle on this dispute is whether there are 'qualia'. Those who think that phenomenal character of conscious experience goes beyond the intentional, the cognitive and the functional are said to believe in the qualitative properties of conscious experience, or qualia for short. (pp 19).

Though there is much to agree with this assertion, it is clear that this problem is broader than these two positions. For example, there are philosophers (Place, 1956,1988; Smart, 1959; Armstrong, 1968) who argue that a straight forward physicalist reduction account can be given of consciousness and others who despair of such an account ever being available, even if they dont support dualism. (McGinn, 1989, Nagel,T. 1998). There are others who maintain a strong dualist account of consciousness (Foster, 1991, Chalmers, 1996). Jackson (1997) argues that the situation is even more complex in that:

> much of the contemporary literature on conscious experience revolves around three questions. Does the nature of conscious experience pose special problems for physicalism? Is the nature of conscious experience exhausted by functional role? Is the nature of conscious

experience exhausted by the intentional contents or the representational nature of the relevant kinds of mental states? (p. 1).

13.2 The Explanatory Gap and Qualia

I have already briefly mentioned Levine's (1983) concept of an explanatory gap. (Chapter 7.2). I propose to discuss this concept in more detail and particularly in relation to Virsu and Laurinen's (1977) experiments on AI's.

Levine (1994) makes an interesting confession. He states:

> I will begin with a confession: I am a qualophile. By 'qualophile' I mean someone who finds that the phenomenon of conscious, qualitative experience....there being something it's like to see colors, tastes, feel emotions, and even entertain thoughts... poses a challenge to a materialist account of the mind. (p. 107).

Levine (1994) distinguishes two sorts of qualophile: modest and bold. The bold qualophile asserts that we can tell, through a priori reflection on the nature of consciousness, that no materialist account of it could be true. We can just perceive that conscious experience has certain features which make it incompatible with any description proposed in terms of the natural sciences: " Conscious experience is just not, in this sense, a natural phenomenon " (Levine, 1994, p. 107).

Levine (1994) says that he is a modest qualophile, who makes no strong, positive claim of the sort asserted by the bold qualophile. The modest qualophile finds the nature of conscious experience to be a source of deep puzzlement. She finds that no materialist theory seems to explain our experience, to make intelligible how a system satisfying the materialist's description could be a subject of conscious experience. This puzzlement occurs, according to Levine, because there is an explanatory gap in any materialist account of qualitative experience. Levine (1991) argues that:

> The principal problem with a materialist reduction of the qualitative character of experience (such as the 'look' of a red rose) is the fact that physicalist (or even functionalist) descriptions of sensory experience do not explain the qualitative character of those experiences. An alleged materialist reduction would accomplish this explanatory feat if it were possible to understand why a state with just these physical/functional properties should be experienced as of this qualitative character. That is, even if we could verify that experiences of red were perfectly correlated with the subject's going into some particular physical state, call it 'Pr', we would not have explained the experience unless we could understand why the particular properties of Pr should experientially manifest themselves in the ' reddish' way they do. In a previous paper (Levine, 1983), I tried to show that in fact no such understanding could come from a physicalist account. On the contrary, I argued, that there exists an unbridgeable ' explanatory gap' between the physical and the mental (i.e. qualia). (p. 27).

Levine (1983) modestly asserts that:

> one cannot conclude from my version of the argument (the explanatory gap) that materialism is false......nevertheless, it does, if correct, constitute a problem for materialism, and one that I think better captures the uneasiness many philosophers feel regarding that doctrine. (p. 354).

Levine is indeed being modest because Chalmers (1996) has readily used the notion of the explanatory gap in his falsification of materialism and the espousing of a form of dualism through his conceivability argument of zombies. Thus Chalmers asserts:

> The very fact that it is logically possible that the physical facts could be the same while the facts about consciousness are different shows us that as Levine (1983) has put it, there is an explanatory gap between the physical level and conscious experience. If this is right, the fact that consciousness accompanies a given physical process is a further fact, not explainable simply by telling the story about the physical facts. (p. 107).

Thus Levine's concept has had greater impact than he imagines. This raises the question of why it has been so powerful? I would like to argue that it has been so powerful because there has not been a clear cut case of a reductive account of a conscious event that meets Levine's criterion that it also explains the conscious event. Why has this been so? It would appear to me that there are two methodological problems to be overcome before both a reduction and an explanation can be achieved. Firstly, it must be shown that the physical event is both a necessary and a sufficient condition for the conscious event, and that the physical processes can be reversibly manipulated into and out of the necessary and sufficient conditions. Now this is not a situation that has been achieved in studies of the human nervous system. For example, lesion studies have only shown that part of the nervous system might be the only necessary condition for a conscious event. For example, many stroke studies have shown recovery of function over time, thus indicating that other parts of the nervous system have become the necessary condition. Also, scanning and imagining methods applied to the human nervous system (such as Positron Emission Tomography (PET) and functional Nuclear Mangnetic Resonance Imaging (f NMRI)) have only shown possible sufficient conditions for conscious events. Furthermore, recent evidence suggests that these methods do not reliably detect sufficient conditions in all cases (Van Orden and Paap, 1997; Stuffelbeam and Bechtel, 1997).

Secondly, Levine (1995) stresses another methodological problem, which he calls 'the complexity gambit'. He points out that most qualia are unstructured; for example the colour red appears to be simple without any obvious structure. Instead, Levine argues that:

> The idea is supposed to be that by finding structure inside qualia we will better be able to connect qualia to their underlying neurophysiological realizations. (p. 281).

Levine (1995) argues against this move. He claims that:

> The problem is that this just displaces the explanatory gap, instead of removing it. Structure is a matter of relations among elements, which are themselves either structured or simple. To avoid an infinite regress, it is

> clear that whatever set of relations individual qualia are analysed into, the relata must themselves be simple elements of experience. Whether red is a simple, or warmth is, something experiential has to be. So long as experiential primitives are themselves intrinsic properties of experience, the explanatory gap will remain. (p. 281).

However, Levine does not consider the case were the elements of the qualia are clearly correlated or even identical with aspects of the stimulus that can be physically specified. I want to consider one such case by a more detailed analysis of the work of Virsu and Laurinen (1977) that I briefly referred to in Chapter 12.3.2.

13.3 The Explanatory Gap and AI's.

The work I will be referring to now will not only bridge the explanatory gap, but will indicate a type-type reduction of a sensory state to a brain process; in other words a mind/ brain identity. Therefore, I will commence with some discussion of identity theory (IT).

13.4 Identity Theory and Qualia.

Bechtel and Mundale (1999) have argued that the view that psychological states are multiply realizable has become orthodoxy in the philosophy of mind. This claim of multiple realizability is the claim that the same psychological state can be realized by different brain states, and thus that there could no identity relation between types of brain states and types of psychological states. Heil (1999) has argued that:

> Multiple realizability has been a central theme in anti-reductionist arguments designed to show that the mental is not reducible to the material. (p.189).

Block and Fodor (1980) emphasize this problem by arguing that:

> it is possible that the type-to-type correspondence required by behaviorism or by physicalism should turn out to obtain. The present point is that even if behavioral or physical states are in one-to-one correspondence with psychological states, we have no current evidence that this is so. (p. 238-239).

This has led to an enormous literature in which either functionalist token-token identity or non-reductive supervenience is proposed instead of type-type identity (Kim, 1992; Macdonald, 1992; Jackson and Pettit, 1990). The aim of this section is to suggest that despite these theories, a type-type identity relation can be given for some psychological states, as suggested by early identity theory.

It is worth while examining the identity theory again, since Bechtel and Mundale (1999) conclude " that the claim that psychological states are in fact multiply realized is unjustified " (p. 177). Modern identity theory commenced because an Australian school of materialist philosophy was developed at Adelaide University, ironically, by two Englishmen, with he help of an American (Martun). (Place, 1956, Smart, 1959). The approach assserted an identity between mental processes and brain processes. Both Place and Smart confined their identity theory (IT) to sensations, but later Australian philosophers (Armstrong, 1968) extended the concept to all mental processes, such as thinking and feeling. This section will confine itself to the case of sensations.

Place (1956) argued that cognitive concepts such as knowing, believing, remembering and volitional concepts such as wanting and intending could be given a dispositional account. But he said:

> on the other hand, there would seem to be an intractable residue of concepts clustering about the notions of consciousness, experience,

sensation and mental imagery, where some sort of inner process story is unavoidable. (p. 44).

Place (1970) argues that:

> The thesis that consciousness is a process in the brain is put forward as a reasonable scientific hypothesis not to be dismissed on logical grounds alone. (p. 42).

Place (1956) points out that even famous physiologists, such as Sir Charles Sherrington concluded that an identity could not be found as there are " two continuous series of events, one physico-chemical, the other psychical, and at times interaction between them" (Sherrington, 1947, pp. xx-xxi). Place argues that this is due to what he calls the 'phenomenological fallacy'. He says that:

> This logical mistake...is the mistake of supposing that when the subject describes his experience, when he describes how things look, sound, smell, taste, or feel to him, he is describing the literal properties of objects and events on a peculiar sort of internal cinema or television screen, usually referred to in modern psychological literature as the 'phenomenal field.'. (p. 49).

Place concludes that the real situation is the reverse of this:

> We learn to recognize the real properties of things in our environment. We learn to recognize them, of course, by their look, sound, smell, taste and feel.... it is only after we have learned to describe things in our environment that we learn to describe our consciousness of them. (p. 49).

He then argues that once we rid ourselves of the phenomenal fallacy we realize that the problem of explaining introspective observations in terms of brain processes is far from insuperable. He then asserts a claim that was taken up by Smart (1959) that:

> when we describe an after-image as green, we are not saying that there is something, the after-image, which is green; we are saying that we

are having the sort of experience which we normally have when, and which we have learned to describe as, looking at a green patch of light. (p. 49).

It is interesting that this paper has been so influential, yet it nowhere discusses any evidence relating to how an identity would be realized or confirmed or even identified.

Smart (1959) extended and defended Place's position. In doing this Smart answered a number of objections to the proposed identity. Objection 3 stated that while it might be possible to get out of asserting the existence of irreducibly psychic processes, one could not get out of asserting the existence of irreducibly psychic properties. Smart's main reply to this was to expand Place's notion of not having an after-image but instead having an experience of an after-image. This reply introduced Smart's concept of topic neutrality. He says:

> when a person says 'I see a yellowish-orange after-image', he is saying something like this: ' There is something going on which is like what is going on when' I have my eyes open, am awake, and there is an orange illuminated in good light in front of me, that is, when I really see an orange...... notice that the italicised words, namely ' there is something going on which is like what is going on when' are all quasi-logical or topic-neutral words. (p. 149).

To objection 4 that an after-image is not in physical space, but a brain process is, so therefore the after-image cannot be a brain process; Smart replied as follows:

> It is the experience which is reported in the introspective report..... there is, in a sense, no such thing as an after-image or a sense-datum, though there is such a thing as the experience of having an image, and this experience is described indirectly in material object language, not in phenomenal language, for there is no such thing. (p. 150-151).

It is important to note that Smart like Place assumes that the thesis is a scientific hypothesis, although Smart concedes that no conceivable experiment could decide between materialism and epiphenomenalism. But also like Place, Smart does not examine any scientific evidence for the hypothesis or consider how it could be tested, he simply asserts that Occam's razor is sufficient. He says:

> If it be agreed that there are no cogent philosophical arguments which force us into accepting dualism, and if the brain-process theory and dualism are equally consistent with the facts, then the principles of parsimony and simplicity seem to me to decide overwhelmingly in favour of the brain-process theory. (p. 156).

However, I would like to argue that the evidence I presented in Chapter 7.0 could show a difference between materialism and epiphenomenalism. In this evidence I pointed out that things like AI's and simultaneous contrast colour (SCC) could be shown to act like external colours. Anstis et al., (1978) demonstrated that SCC could produce an AI when a grey area was surrounded by red, then a SCC of green was produced in the grey area. This SCC green would produce a red AI, if it was inspected for some time. Also, Anstis et al., (1978) showed that an AI could produce a SCC. If an AI was induced in a surround area, then this would produce a SCC in the surrounded grey area. Also, Day and Webster (1989) used an AI to produce a McCollough effect in black and white gratings. This effect is nor another AI as it is orientation sensitive, in that it changes colour when the head is rotated, which is something an AI does not do. This evidence shows that both AI's and SCC's have causal relations with external stimuli, and they have been cited by Campbell (1993) as being the two main reasons for possibly having a subjective account of colour. He argues that simultaneous contrast colour and opponent processing (here in the form of AI's) present objective accounts the most trouble. He does not cite them as cases of epiphenomena, although he is in favour of such accounts (Campbell, 1970). Campbell (1982) says that

> The new Epiphenomenalism rejects only one half of the interaction of matter and spirit, This being so, one who holds to the theory must just grit his teeth and assert that a fundamental, anomalous, causal connection relates some body processes to some non-material processes.

He must insist that this is a brute fact we must learn to live with, however inconvenient it might be for our world-schemes. (p. 118).

However, these two items do appear to be ideal candidates for qualia or non-material processes and fit in with Jackson's (1982) argument that:

> it is possible to hold that certain properties of certain mental states, namely those I have called qualia, are such that their possession or absence makes no difference to the physical world. (p. 133).

As further support for my argument that these two processes have causal relations, the next sections will endeavour to show that a mind/brain identity can be given for AI's.

In Borst (1970) are published a number of papers criticising Smart's position. Shaffer (1970) makes some important points about the criteria that are needed for mind / brain identity to be successful. He argues that there are three necessary conditions for this type of identity and the three conditions are jointly sufficient. The three conditions are that the two terms of an identity must (1) be located in the same place, (2) must occur at the same time and (3) the presence of one must be an (empirically) necessary condition for the presence of the other. Neither Smart nor Place has considered these criteria.

Rorty (1970) proposes even more stringent criteria for identity. He asserts that:

> (1) that one-one or one-many correlations could be established between every type of sensation and some clearly demarcated kind(s) of brain processes; (2) that every known law which refers to sensations would be subsumed under laws about brain processes; (3) that new laws about sensations be discovered by deductions from laws about brain processes. (p, 190).

Taylor (1970), in his attack on Smart's identity theory, takes a very pessimistic view about the possibility of such identities. He says that:

> Even granting that we may be able to account for behaviour by laws and conditions expressed exclusively in physiological terms, it does not follow that we can discover correlations between, say, after-images and

> brain states, or physical sensations and states of the body. For there is nothing that guarantees that a given after-image, judged the same on repeated occurrences in virtue of its phenomena properties, will always be accompanied by the same brain state, or even finite disjunction of brain states. (p. 235).

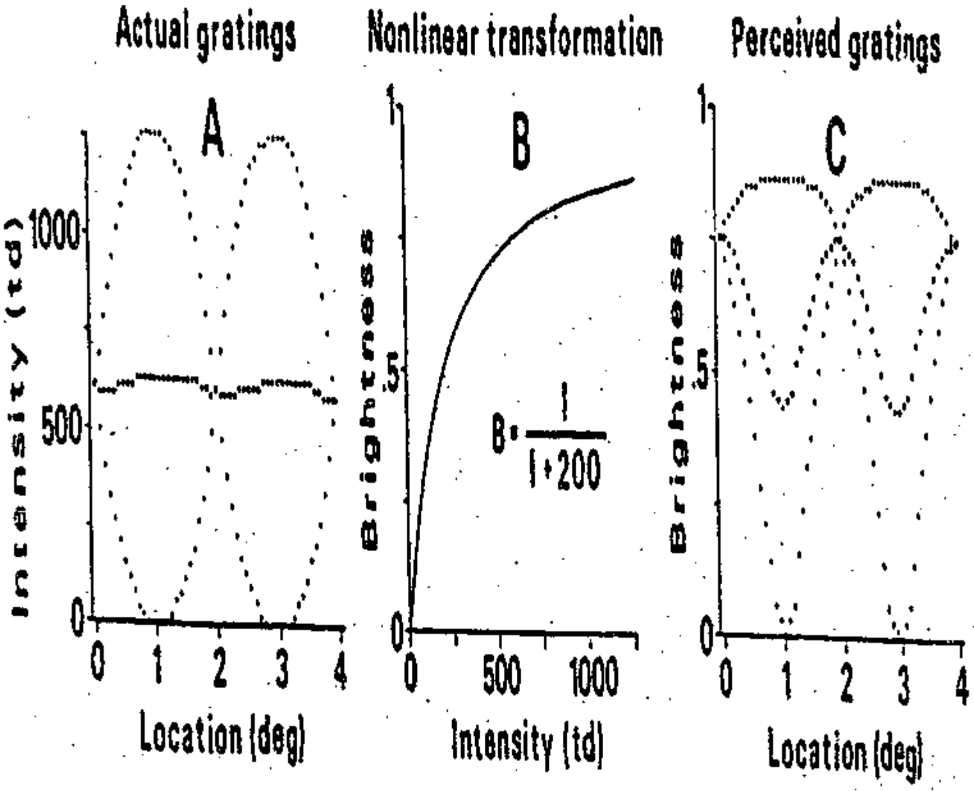
It is proposed to cite evidence about after-images (AI's) that will meet these criteria for identity.

13.5 The Work of Virsu and Laurinen.

Although the AI has been extensively discussed in the philosophy literature (Armstrong and Malcolm, 1984; Smart, 1959, 1995; Boghossian and Velleman, 1989; Bigelow et al. 1990), there has been little analysis of the relevant after-image literature. In an important study, Virsu and Laurinen (1977) have shown that there are two types mechanisms for an AI, each with a different location in the visual system. They employed the technique of reversible pressure blinding of the eye, which was applied either during or after the adaptation producing negative AI's. This pressure blinding was achieved in less than 30 sec by pressing the lateral canthus by a finger supported against the zygomatic bone. There are two sources of blood supply to the eye (Brown, 1968). The pressure blinding blocks the retinal blood supply but does not block the blood supply to the receptors, which arises from the choroid blood supply. (Brown, 1968). Virsu and Laurinen (1977) found that pressure blinding did not affect long lasting negative AI's produced by intense stimuli, which also produced photochemical bleaching in the receptors. They called this AI the " bleaching image" and it was thus identified as occurring in the receptors. However, when weaker, non-bleaching stimuli were used then pressure blinding prevented any negative AI being produced. Thus this AI was occurring in the neural part of the retina, most likely in the ganglion cells, as these degenerate and disappear when the retinal blood supply is blocked (Brown, 1968). They called this negative AI the " sensitivity image". When pressure blinding was applied after a negative AI was formed to either an intense or a moderate stimulus, then all AI's were obliterated. This indicates that the negative AI was not present more centrally than retinal ganglion cells, as it would still have been seen against what is called the subjective grey colour produced by pressure blinding (Virsu and Laurinen, 1977). These results show that the neural mechanisms are the necessary and sufficient conditions for the moderate negative AI's and indicate that these AI's are identical to the brain processes. Such a result has not been shown for any other mental process, and is important as Lycan (1987) suggests that an AI is a paradigm case of a quale.

In another very clever experiment, Virsu and Laurinen (1977) produced an illusory negative AI to sine-wave gratings, which could be explained by the non-linearity in the visual system. They adapted with a counterphase-modulated (i.e. each grating was 180^0 out of phase with the preceding grating) sine-wave grating of high contrast and moderate intensity. When they adapted with this grating unmodulated it produced a negative AI with the spatial frequency of the grating. When they adapted with the modulated grating then the AI had double the spatial frequency of the grating. During this counterphase adaptation, only the spatial frequency of the grating was observed. If the visual system was linear, then no AI would be produced by counterphase modulation because the 180^0 difference in phase would lead to a cancellation of the AI due to the lining up of the maximum and the minimum of the two presentations of the grating. (Figure 20A). The non-linearity did not allow this cancellation and an illusory doubling of frequency was seen. This AI was also prevented from occurring and abolished after induction by pressure blinding so it also has a retinal neural origin. When intense stimuli, like those used by Craik (1940), were employed, then no illusory AI could be generated (Virsu and Laurinen, 1977) suggesting that cancellation had occurred because of linearity that was present in the receptors. Thus, this illusory AI can also be regarded as identical with the neural processes as it is located in specific neural structures and depends on the non-linear properties of these structures. Virsu and Laurinen (1977) also showed that coloured negative AI's were prevented from occurring by pressure blinding, but they did not test for illusory coloured AI's. In some unpublished experiments, I was able to induce illusory, complementary coloured negative AI's. The combination of these two sets of results suggest the challenging conclusion that the colour mechanisms behind negative AI's induced by coloured sine-wave gratings are located in the retina

Fig. 20 A; (A): the actual counterphase sine-wave grating as a function of intensity leads to a cancellation effect; (B): the non-linear transformation employed; (C): the perceived gratings showing the effects of the non-linearity in which there is no cancellation but a doubling of the spatial frequency. (adapted from Virsu and Laurinen, 1977).



Actual gratings
Nonlinear transformation
Perceived gratings
A
B
C
Intensity (td)
1000
500
0
0 1 2 3 4
Location (deg)
Brightness
1
.5
0
0 500 1000
Intensity (td)
B = I / (I + 200)
Brightness
1
.5
0
0 1 2 3 4
Location (deg)

This is challenging because it suggests that colour and orientation and spatial frequency mechanisms have got together in the retina without any of the complex cortical mechanisms that are said to be required for the binding of features of stimuli (Treisman, 1996; Marlsburg, 1995; Singer and Gray, 1995).

Let us look at these data with regard to the criteria for identity outlined above. With regard to Shaffer's three criteria, the results are quite clear cut. The experience of having the AI occurs at the same time as the neural process. It also occurs in the same place and the presence of one, the neural processes, are (empirically) necessary conditions for the presence of the other, as no illusory AI is found with intense stimuli. Thus it is essential that the conditions of moderate stimuli, counterphasing and non-linearity are present to achieve the illusory AI. Also, the abolition of the AI after induction indicates that some neural conditions are necessary for the AI.

Even, Rorty's more stringent criteria appear to be partly met. There is (1) a one-one correlation between types of sensation (e.g. the three types of AI: illusory, moderate intensity stimuli and intense stimuli) and some clearly demarcated kinds of brain processes; (2) while not every known law which refers to sensation can be subsumed under laws about these brain processes, some generalizations about the particular AI could be generated; e.g. the location, the timing and the nature of both the illusory AI and the standard AI to moderate stimuli can be predicted from the neural properties; (3) a new law about sensations can be generated by the new prediction of an illusory AI, which was not known about before these experiments. Virsu and Laurinen (1977) using a computer method were able to measure the spatial frequency of the negative AI's, thus giving a third person measure of a sensation. In some unpublished experiments, I have been able to replicate their results and measure the spatial frequency of these " Sensitivity " and illusory AI's. Thus, for the first time a third person account can be given of sensations.

Identity theorists have been challenged to account for the asymmetry between first-and third-person access to mental states (Braddon-Mitchell and Jackson, 1996). The work discussed here shows for the first time for sensations or qualia that they can be identified with brain processes and also shown to be third person accessible. That is, the same sensation is measured across subjects as they all show the doubling of grating spatial frequency.

With regard to Taylor's pessimistic predictions, these also appear to be met. Taylor said that:

> nothing guarantees that a given after-image, judged the same on repeated occurrences..... will always be accompanied by the same brain state....whenever it occurs in the biography of one person, let alone in all human beings. (p. 235).

Instead, we find that the same brain state accompanies these moderate AI's, both illusory and non-illusory. Also we can show objectively that the same AI or sensation (i.e doubling of frequency) occurs in all subjects. It should be stressed again that this is the first case of a clear cut identity between a mental state or sensation and a sharply localized brain process. The pressure blinding has allowed us to reversibly manipulate a specific brain area and specific cells to produce predicted changes in sensations. As Craik and Vernon (1941) have pointed out this reversibility is important as it " furnishes a convenient 'tap' between eye and brain which can be turned on and off at will " (p. 70). We can thus show that a neural retinal process is both a necessary and a sufficient condition for the illusory AI and this can be repeated both within the same subject and across different subjects. This type of manipulation has not been possible using other types of interventions. For example, studies of blindsight (Weiskrantz, 1986) have shown that visual cortex VI is part of a pathway involved with visual consciousness, but it does not show that the sensations are generated there. In the case of the AI, the fact that the AI can be abolished after its generation shows that the site of generation is not more central than the retina and it is not a case of a simple blocking of impulses to other areas where the AI is being produced. It is not possible to show this with either lesion studies or blindsight studies as the changes cannot be reversed. Even modern imaging studies using positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) scans can show only a correlation and at best a sufficient condition for any sensation. In fact recent analyses of these techniques (Van Orden and Paap, 1999; Stuffelbeam and Bechtel, 1997) have suggested that:

> imaging studies do not reliably converge on the same brain regions, and cognitive studies do not discover the same components across tasks. No cognitive variable shows its effects identically in different task contexts. Instead, every cognitive variable that might indicate a cognitive component reliably interacts with other variables, and the pattern of interaction change across tasks..... perhaps this is why no single cognitive component has yet been discovered for which there is general agreement among investigators. (Van Orden and Paap,1999, p. S90).

This is not meant by me to disparage the possible use of these methods, but it does suggest in our particular case we have a unique situation in the identity literature, in that we can state the specific neural structures and their properties and relate them to specific cognitive or sensation properties in a reversible manner.

13.6 The Illusory AI and the Explanatory Gap

The illusory AI has very important implications for the concept of an explanatory gap in the explanation of consciousness by brain processes (Levine, 1983,1994). Using pain and C-fibres firing as an identity example, Levine (1983) argues that this identity has an explanatory gap as it does not say why pain should feel the way it does. Levine argues that there is a deep problem about how we can explain the distinctive features of mental states in terms of their physical properties. For example he asks why a surface with a particular spectral character should look blue. Levine wants to argue that no matter how much we know about neural mechanisms we will never know why we have the phenomenal properties that we do have. He says:

> For a physicalist theory to be successful, it is not only necessary that it provide a physical description for mental states and properties, but also that it provide an *explanation* of these states and properties. In particular, we want an explanation of why when we occupy certain

physico-functional states we experience qualitative character of the sort we do......why it is like what it is like to see red or feel pain. (Levine, 1994, p. 128).

These are important considerations, but the illusory AI appears to be the first neural case, which does not have such a gap. The neural explanation tells us what the AI should look like i.e. double the spatial frequency of the sine-wave grating. Unfortunately, there does appear to be a gap with other simpler phenomenal features, particularly colours. However, the illusory AI appears to refute Nagel's (1998) claim that:

> I believe that the explanatory gap in its present form cannot be closed.... that so long as we work with our present mental and physical concepts no transparently necessary connection will ever be revealed between physically described brain processes and sensory experience. (p. 344).

The illusory AI appears to be an answer to Levine's 'complexity gambit'. The properties of the sensory experience can be objectively measured and directly related to the physical property of the adapting sine-wave, e.g. the spatial frequency. This would appear to overcome Levine's objection that we would still have an experiential element to be explained and hence the gap would still be present. The establishment of both necessary and sufficient conditions and the explanation of the doubling of frequency by the neural properties clearly overcomes the gap in this case.

The results have also some implications for a current important theory about consciousness which is largely based on an explanatory gap (Chalmers, 1996). Chalmers says that:

> no matter what functional account of cognition one gives, it seems logically possible that that account could be instantiated without any accompanying consciousness.... consciousness may in fact arise from that functional organization in the actual world..... but the important thing is that the notion is logically coherent. If this is indeed logically possible, then any functional and indeed any physical account of mental phenomena will be

fundamentally incomplete. To use a phrase coined by Levine (1983), there is an explanatory gap between such accounts and consciousness itself. Even if the appropriate functional organization always gives rise to consciousness in practice, the question of why it gives rise to consciousness remains unanswered. (p. 47).

At least in the case of the illusory AI, we can give an answer to Chalmers's "why". In this one case, we can say why consciousness (the spatial frequency) looks the way it does. A large part of the strength of Chalmers's argument has come from our inability to give one case that appears to explain consciousness in neurological terms. If other cases could be found like the AI case, then a reductive account of consciousness might be achieved instead of Chalmers's proposal " that materialism is false and that a form of dualism is true" (Chalmers, 1996, p.XV).

The illusory negative AI also suggests that the problem of multiple realizabilty need not be a general one. Fodor (1997) argues that it is general and says that:

> I am strongly inclined to think that psychological states are multiply realized and that this fact refutes psychophysical reductionism once and for all. (p. 149).

It is possible to argue that these experiments have shown that AI's are multiply realized. What has been shown is that there are two types of AI (to either intense or to moderate stimuli), which are located in different structures and thus each is singly realized. The fact that the negative AI to moderate stimuli can be prevented from occurring by blocking activity in one area and it can be abolished after it is induced clearly indicates that it is realized in the one place. It should be stressed that these AI's are long lasting (e. g. 3-4 minutes after the primary stimulus is removed), so its abolition indicates that this long process is not occurring more centrally than retinal ganglion cells or in any other location. Both the standard AI and the illusory one to moderate stimuli are clearly not cases of multiple realization. The concept of multiple realization was first put forward by Putnam (1980). He based his argument on pain as instantiated in mammals, reptiles and mollusca and suggested that these organisms would not be likely to be in the same brain state when they experience pain. Putnam (1980) asserts even more strongly that:

> if we can find even one psychological predicate which can clearly be applied to both a mammal and an octopus (say " hungry "), but whose physical-chemical " correlate " is different in the two cases, the brain-state theory has collapsed. It seems to me overwhelmingly probable that we can do this. (p. 228).

While it does seem likely that across species comparisons will not support an identity claim, Bechtel and Mundale (1999) claim to have shown that skepticism about neuroscience's role in understanding cognition or sensation is misguided and that the apparent success of multiple realizability is based on methodological error. This error is based on a mismatching of a broad-grained criterion for psychological states with a fine-grained criterion for brain states. They claim that if the grain is made equal that multiple realizability is not so prevelant either across species or in the one species. In the situation discussed in this paper, we have two clear cases of single realizability in humans, clear cases of type-type identity. It would seem to us that it is the lack of other reversible methods like pressure blinding to manipulate specific brain structures that is holding back physicalist or identity explanations.

Finally, we should say something about Smart's concept of topic neutrality. The topic-neutral approach has been heavily criticized by a number of philosophers (Bradley, 1964; Jackson, 1977; Rosenthal, 1976). Rosenthal (1976) argues that the topic neutral translation of Smart and Armstrong has tried to address what he calls the 'irreducibly psychic properties' (IPP) objection to materialism. Rosenthal claims that their approach is one of semantic translation of predicates. When a theoretical reduction translation based on neural laws is needed. Rosenthal (1976) asserts that:

> It is reasonably clear and uncontroversial what empirical results would show that mental events are neural events; temporal and causal correlations, and the ability to explain and predict events by appeal to those correlations, should suffice. (p. 396).

These points are very similar to the criteria for identity mentioned above. However, there has been no systematic successful attempt in either the philosophy or the physiology literature to see whether visual science supports a reductive approach to such mental properties. While the above findings on the AI support the reductive concept, some other studies of the AI also give direct support to the concept that something is going on with the AI that normally goes on when an object is before one. As I mentioned earlier in Chapter 7.0, Anstis et al. (1978) showed that AI's could act like external colours and produce simultaneous colour contrast effects. Also, Day and Webster (1989) showed that AI's could act like external stimuli. an after-effect. This suggests that Smart could be correct in proposing the translation that something is going on with an AI, which is like what goes on when an external coloured object is present.

In conclusion, the studies of the AI discussed here show that a mind / brain identity explanation can be given for some mental / sensation processes. It indicates that materialism is not necessarily false, as suggested by Chalmers (1996). It is suggested that if other techniques, with the selective and reversible control of pressure blinding, (perhaps other 'taps' (Craik and Vernon, 1941)) could be found and employed, then a more general identity theory could be established incorporating other mental processes.

CHAPTER 14.0

14.1 Consciousness and Qualia as Representations.

Armstrong (1996b, unpublished) has argued for a new thesis about mentality. He originally held a thesis (Armstrong, 1996a) with Lewis (1966), that the true concept of the mental is that which plays a certain causal role or roles. Perceptions, for instance, are considered to be effects in the perceiver apt for being produced by certain sorts of stimuli, and as causes apt, in suitable circumstances, to play their (informational) part in causing certain behaviour. Armstrong claims that the thesis to be substituted as a starting-point is not in any way opposed to this Armstrong-Lewis thesis, but is more specific, linking up directly with intentionality. The thesis is that mental states, events and processes, as we experience them, are nothing but representional states. Perceptions are representing states, representing to us our present environment. This leads to a conclusion that there are no non-material things like qualia (Armstrong, 1979).

Armstrong says that his recent appreciation of this new starting point came from reading Michael Tye's book, entitled Ten Problems of Consciousness (1996a). Tye (1996a) argues that he is not offering a general theory of consciousness but what he calls 'phenomenal consciousness', in which the central case is perception. His slogan is that Qualia or " phenomenology ain't in the head " (p. 151).

Tye is worried about what he calls perspectival subjectivity. According to Tye such states are:

> phenomenally conscious states,then, are subjective in that fully comprehending _them requires a certain experiental point of view. In that way, they are perspectival. But physical states are not perspectival. (p, 13).

Tye feels there is a problem of mechanism in this issue. For Tye:

> Neural states are not themselves perspectivally subjective. But phenomenal states are. Somehow, physical changes in the soggy gray-and-

white matter composing our brains produce feeling, experience, 'technicolor phenomenology' (McGinn, 1991). How is it that items that are generated by non-perspectival items can be perspectival? What is it about the brain that is responsible for the production of states with a perspectival subjective character? (p. 15).

Tye runs these two problems together under the banner of the explanatory gap (Levine, 1983). He highlights the puzzling nature of the gap by an amusing quotation from T. H. Huxley:

> How it is that anything so remarkable as a state of consciousnes comes about as a result of irritating nervous tissue, is just as unaccountable as the appearance of Djin when Aladdin rubbed his lamp. (Tye, 1996a, p. 15).

I believe I have shown one answer to the explanatory gap in the case of AI's discussed in chapter 7.2 and 13.0. In the case of illusory AI's, the subjective nature of the AI was predicted from the non-linearity in the visual components. Thus the subjective nature of the experience could be explained and no gap was present. There might not be other cases available at present but this case shows that it is possible to overcome the gap if we could devise similar techniques to pressure blinding. Thus perspectival subjectivity could be predicted and explained by neural mechanisms. (Webster, 2001a).

Tye, however, wants to overcome the gap and perspectival subjectivity by evoking his PANIC theory of phenomenal character. PANIC stands for Poised Abstract Nonconceptual Intentional Content. It is this theory which has caused Armstrong (1996a, unpublished) to change his view about a starting point for mentality. Tye claims that it answers all of his ten problems. Armstrong (1996a) likes the theory because of its emphasis on intentionality. Previously, Armstrong (1968) had argued that perception and phenomenal content was a matter of having beliefs about the world. He prefers Tye's PANIC theory because it acts before the belief system. In other words, it provides information to the belief system through its representations.

14.2 PANIC THEORY

A major problem for Tye's theory is the concept of phenomenal content, which Tye argues is the one and the same as phenomenal character (p. 143). In explaining phenomenal content, Tye has a complex argument about representation, which I don't think Armstrong has realized. Unfortunately, I need to use extensive quotations to make clear of what Tye's argument actually consists.

Tye says:

> Sensory representations serve as inputs for a number of high-level cognitive processing. They are themselves outputs of specialized sensory modules (for perceptual experiences, bodily sensations, primary emotions, and moods) Representations occurring within the modules supply information the creature needs to construct or generate sensory representations, but they are not themselves sensory. Phenomenal content, in my view, is not a feature of any of the representations occurring within sensory modules..... experience and feeling arise at the level of the outputs from the sensory modules and the inputs to a cognitive system. It is here that phenomenal content is found. (Tye, 1996a, p. 137).

I find this quotation to be most difficult, and the difficulty is not mentioned by any commentator on Tye's book. (Armstrong, 1996a; unpublished; Levine, 1997b; Block, 1998; Jackson, 1998; Shoemaker,1998). My difficulty is that Tye is arguing for two types of representation which are difficult to comprehend. Firstly, he says there are representations occurring in the sensory modules which are not themselves sensory. Secondly, these representations supply the information for sensory representations. The latter representations are said to comprise phenomenal character which is one and the same as PANIC (Poised Abstract Nonconceptual Intentional Content). The phenomenal character or content (PC) is poised in a double position. It is understood first as requiring its contents as attaching to the (fundamentally) maplike output representations of the relevant sensory modules and poised secondly to stand ready and in position to make direct impact on the belief/desire system (Tye, 1996a, p. 138). PC 's are abstract in the sense that no particular concrete objects enter into these contents. PC is the representation of general features or properties. The contents of PC are nonconceptual, thus saying that the general features need not be ones for which their subjects posses matching concepts. An intentional mental state according to Tye is a:

> state that (a) can represent or be about an F without there being any particular F that it represents or is about, indeed without there really existing any F's at all, and (b) is fine-grained in at least one of the ways specified above with respect to the manner of its representation. Uncontroversial examples of such states are hoping, believing, desiring, thinking, wondering, intending. The intentional content of any particular instance of one of these states is what is hoped for, believed, desired, and so on. In the case of beliefs, the content is expressed in the 'that-clause' used to specify the particular belief. Thus, if I believe that snow is white, what I believe, namely, that snow is white, is the intentional content of my belief.. (Tye, 1996 a, p. 96).

What I find difficult is that PANIC is intentional but it occurs before the belief system and yet the above quotation has intentional content as one of those states involved in hoping, believing and desiring.

According to Tye:

> phenomenal states lie at the interface of the nonconceptual and conceptual domains. It follows that systems that altogether lack the capacity for beliefs and desires cannot undergo phenomenally conscious states. For systems that have such a capacity, the sensory or phenomenal states differ from the beliefs in their functional role, their intentional contents, and their internal structure. (p. 144).

Thus, we have a three level system. First, we have a representation at the level of the sensory modules that are not themselves sensory. (how can this be?). Second, we have intentional sensory representations (PANIC) that are outputs of the specialized sensory modules and are poised before the belief system. Third, we have intentional content in the cognitive system. Armstrong (1996a,unpublished) says that Tye's:

> representational account is, of course, to be distinguished from the old Representational theory of perception where the mind gazes internally at a sense-datum which may or may not represent reality correctly. (p. 4, n 4).

But with so many representations in line this claim might be hard to justify!

In this context, let us look at the representational output of the sensory modules, concentrating on Tye's account of vision. Once again I am forced into quotations as the most concise method of explaining what Tye says:

> On the standard computational approach, the receptor cells on the retina are taken to be transducers. They have, as input, physical energy in the form of light, and they convert it immediately into symbolic representations of light intensity and wavelength. These representations are themselves made up of active nerve cells. Hence, they are physical. And they are symbolic, since they are the objects of computational procedures. Moreover, they represent light intensity and wavelength, since that is what they reliably track, assuming the system is functioning properly. The computational procedures operating on these representations generate further symbolic representations [my emphasis] first of intensity and wavelength changes, then of lines of such changes [further representations?], then of edges, ridges, and surfaces, together with representations of local surface features, for example, color, orientation, and distance away [more representations!] At these early stages, the visual system is much like a calculator that has been hardwired to perform addition. There are no stored representations in memory, whose retrieval and manipulation govern the behavior of the system. So representations are built up of distal features of the surfaces of external objects in mechanical fashion by computational processes. The initial, or input, representations for the visual module track light intensity and wavelength, assuming nothing is malfunctioning. The output representations [more

> representations?] track features of distal stimuli under optimal or ideal perceptual conditions. Thereby, it seems plausible to suppose, they represent those features, they become sensations of edges, ridges, colors, shapes and so on. Likewise for the other senses.......so perceptual sensations feed into the conceptual system, without themselves being a part of that system. They are nondoxastic or nonconceptual states. This, I want to stress, does not mean that perceptual sensations are not symbolic states. But, in my view, they are symbolic states very different from beliefs. (p. 102-104).

In his later precis of his book, Tye says:

> I make a sharp distinction, then, between basic perceptual experiences or sensations, and beliefs or other conceptual states.....Perceptual experiences like these form the outputs of specialized sensory modules, and the inputs to one or another higher-level cognitive system. They arise at the interface between the nonconceptual and the conceptual domains....they supply the inputs to cognitive processes, whose role is to form beliefs directly from them, if attention is properly focused. They are, in this sense, states that are poised (or that have poised contents).... basic perceptual experiences, I claim, have nonconceptual contents, since they are representational or intentional states and their subjects need not have concepts that match what they represent (or enter into their contents).......so, perceptual experiences have poised, nonconceptual, representational or intentional contents and it is in these contents, I maintain, that their phenomenal character is to be found. The appeal here is partly to Occam's Razor: it is not necessary to posit any intrinsic, non-intentional qualia to solve any of the ten problems ... So, non-intentional qualia should be eliminated. (p. 652).

The major difficulties with all of this are the relationships of the different representations with intentionality, the introduction of sensations into the analysis, and the notion of being nonconceptual. Jackson (2002) finds it difficult to understand how nonconceptual can be involved when the emphasis by Tye is on beliefs. According to Jackson, this amounts to the view that beliefs have conceptual content and experiences have nonconceptual content. But Jackson says that:

> Belief is the representational state par excellence. If belief does not represent things are thus and so, I do not know what does. This means that to hold that experience has content in some different sense to the sense in which belief does is to deny rather than affirm representationalism. (Jackson, 2002, p. 21).

Jackson goes on to argue that there needs to be a univocal sense of content, a sense on which content for both beliefs and experiences. Jackson accepts that the issue is complex. He says that:

> My reasons for scepticism about appealing to the distinction between conceptual and nonconceptual content involve highly contentious issues. (p. 24).

He illustrates this with the concept of shape. We need to distinguish two cases. (1) You see something as having a highly idiosyncratic shape but lack a word for it. Here you have the concept but lack a word for it. This you can remedy by either making one or finding out if there already is one. (2) You do not see something as having a shape when it in fact has a shape S. When you are told the word for it you acquire the ability to see it as having S. Jackson says that:

> Your acquisition of the concept changes your perceptual experience. (p. 23).

Jackson (2002) also illustrates the conceptual versus nonconceptual issue with colour. Tye (2000) argues that our colour experiences subjectively vary in ways that far outstrip our colour concepts. Raffman (1995) says that this is due to our memory failings and both Raffman and Tye conclude that this supports a nonconceptual approach. Jackson (2002) says that you can perceptually represent that something i.e. red $_{17}$ without the concept of red$_{17}$, but you cannot represent that something is red$_{17}$ without the concept of red or of colour. (p. 22).

I interpret this to mean that you can't be in a nonconceptual state in this situation.

It is interesting to stress again Armstrong's (1996a, & unpublished comment) that Tye's concept of representation can be distinguished:

> from the old Representative theory of perception where the mind gazes internally at a sense-datum which may or may not represent reality correctly. (p. 4).

Armstrong (1961,1968, 1979), to my mind, demolished both classical Representative and Phenomenal theories of perception, yet he does not apply the same criticisms to Tye's theory. In these criticisms, Armstrong was espousing a direct realist approach to perception, without any role for sense-data or qualia. However, if we look closely at Tye's representations, we see that he has a number of representations before he gets to intentional representations. Most strikingly, the output representations of the sensory modules he argues that:

> they become sensations of edges, ridges, colors, shapes and so on...... so perceptual sensations feed into the conceptual system without themselves being part of the system. (p. 104).

This hardly strikes me as being an example of direct realism with the conceptual system looking at sensations or sense-data as its input. Armstrong like Tye argues that:

> To talk of representations is to talk of intentionality. Representations may represent reality correctly or incorrectly, truly or falsely.... if a mental state represents incorrectly, falsely, then in the terminology of the Scholastics and of Brentano, it has a merely intentional object. A representational account of, say, a hallucination will say that the thing hallucinated does not exist. It is a merely intentional object. (Armstrong,1966b, unpublished comment, p. 4).

But this account of intentionality is still open to the old devestating comment of how do we know what is true about the world if we still depend on representations. (Armstrong, 1968; Maze, 1983) This standard old criticism of representative theories is ignored in the current literature on representation and intentionality (Fodor, 1975,1983; Sterelny, 1990; Braddon-Mitchel & Jackson, 1996, Levine, 1997). This is not an easy problem, but we do seem to need some mechanism to allow us to see the world as it is. (O'Neil, 1958). The " new Representationalists " dispute that there is a skeptical problem at all with representations (Wright, 1993).

It is worth looking at Armstrong's (1961) theory of perception in some detail, as it will help in analysing Tye's theory. Armstrong proposes:

> That perception is nothing but the acquiring of knowledge of, or, on occasions, the acquiring of an inclination to believe in, particular facts about the physical world, by means of our senses. We have already offered an analysis of sensory illusions as a belief or an inclination to believe that we are (veridically) perceiving something. A more profound analysis of sensory illusion may now be offered, corresponding to our proposed analysis of perception. To suffer sensory illusion is to acquire a false belief or inclination to believe in particular propositions about the physical world, by means of our senses. What exactly is meant by the phrase ' inclination to believe something about the physical world' here? In the first place it involves a certain thought or proposition about the physical world...... It is a thought about the world that pushes towards being a belief, but is held back by other contradictory beliefs. (Armstrong, 1961, pp. 105-106).

It is important to look at Armstrong's (1979) analysis of sensation or sense data or qualia, as this will bear on Tye's theory. Armstrong argues that many perceptual statements assert a relation of perception holds between a perceiver and a physical object. Armstrong proposes that the nature of this relationship is one of causation, and this causal relation is a necessary condition for this relation of perception. Armstrong then asks what more is required to yield sufficient conditions for perception. He says that:

> All that seems further required to yield necessary and sufficient conditions for the relation of perception is (i) a condition that ensures that the perception in some way reflects, however distortedly, the nature of the object perceived, and (ii) some restrictions upon the nature of the causal chain that brings the perception to be. (Armstrong, 1979,p. 86).

14.3 Sense data, qualia and causality

Armstrong (1979) looks at how the causal relation can be applied to the Representative theory of perception. In a Representative theory, no physical object or state of affairs is ever immediately perceived. What are immediately perceived are representative or intermediate entities, such as sensations, sense data or qualia. Armstrong points out that:

> the perceived table, or whatever, stands in a certain relation to a sense-datum. This is a causal relation. The table brings the sense-datum into existence. But the sense-datum also stands in some relation to the perceiving mind, or, if the sense-datum is held to be within the mind, to the rest of the mind. That a relation is involved becomes clear when we note that there is never any question for sense-data theorists of a sense-datum being perceived (or immediately perceived, or sensed) yet not existing...... If sense-data always exist, then they must always stand in some relation or other to the mind or the rest of the mind. For Representative theory, then, perception of a physical object involves two relations, a relation of the object to the sense-datum and a relation of the sense-datum to the mind or the rest of the mind. (Armstrong, 1979, p. 88).

What is the nature of the second relation? It seems clear that the relation is a causal one. One can then ask what are the consequences for a Representative theory?

Armstrong (1979) says that if sense-data are causal intermediates, then physical objects act upon the perceiver's sense-organs, which in turn act upon some portion of his central nervous system to produce sense-data or qualia. The sense data then act upon the perceiver's mind to cause perceptions. Armstrong points out that cause and effect are distinct existences. Thus it must be possible for the cause to exist, but not its customary effect or, indeed, any effect at all. It follows that the perception of the sense-datum need not be incorrigible. Armstrong (1979) argues that this result is immensely important. He says:

> once it is granted that the perception of the sense-datum need not be veridical. It can be questioned whether there is any particular reason to postulate sense-data. Historically, one of the major reasons for postulating them has been to provide a non-physical object that is veridically perceived in the case of non-veridical perception of physical objects.......But if it is possible that even the sense-datum should not be veridically perceived, then this traditional motivation for postulating sense-data is removed. This is not to say that the postulation is incoherent, simply that a major reason for making it is gone. (p. 89-90).

Armstrong (1979) argues that if perception and sense-datum are necessarily connected, then the sense-datum is the perception. He says:

> but now the theory is no longer a Representative theory, but a Direct Realist one. For if the sense datum is the perception, it cannot be simultaneously the object of this perception. The perception indeed must have content or intentional object: what seems to be perceived. (p. 96).

Armstrong (1979) says that if we accept his causal analysis of the role of sense data in perception, then he argues that:

> I can find only one argument for postulating sense data which seems to have any force. A case can be made for postulating them as the bearer of the secondary qualitiess. (p. 90).

Armstrong (1979) says that secondary qualities perceptually appear to be qualities of physical objects, or physical states of affairs, or both. However, he points out that:

> there is a line of argument, based on reasonably plausible premisses, which suggests that they cannot be qualities of physical objects. Sense data are then introduced as alternative bearers. (p. 90).

Consequently, Armstrong (1979) proposes that:

> secondary qualities are nothing but....that is identical with......their physical correlates. Colours, and this means perceived colours..... can, I believe be identified with light waves ..... If this 'realistic reduction' of the secondary qualities can be carried through, then I can find no argument for inserting sense data into the perceptual causal chain. (p. 90).

What are these plausible premisses that Armstrong refers to above? In an unpublished paper (Armstrong, 1996b), he argues that:

> There is no place in the physical world for them (secondary qualities) , as the world is at present conceived by our best science. So they will have to go in the mind, will they not? But then it seems the mind is a special place, quite different from that physical object, the brain. (pp. 7-8).

This general problem about the best science is the one I have been stressing. It is based on the visual processes that are supporting the subjective approaches to colour. Armstrong's answer is to argue that the mind is an intentional process. He says that:

> all there is in the mind (as we experience it by introspective consciousness) is the purely intentional registering of the presence of these qualities as qualifying physical surfaces and volumes (for the case of colours), physical spaces and objects for sounds, tastes and smells, locations in the body for pains, itches and so forth. This intentional registering can be mere intentional registering, the extreme cases of mere intentional registering being hallucinations, phantom limbs and so forth. (Armstrong, 1996b, p. 8).

While I agree with Armstrong's conclusion about direct realism and identity of colour with wavelength (i.e. PE/W), it is difficult to apply this model to Tye's theory, with its multiple forms of representation, especially as some representations are based on what look like sense data and these representations occur before the intentional content.

Overall, on the basis of the above arguments, I conclude that Tye has not made an adequate PANIC theory to account for consciousness and for qualia.

It is possible to argue that I have concentrated on the wrong form of representation in stressing Armstrong's earlier views against representations as standing between the observer and the object observed. This new form of represenation eliminates any inner objects or representations and leaves only the representings of objects, that is, we don't observe the representations, we have the representations. The phenomenal character of an experience is its representational content.

Other theorists have proposed that the phenomenal character of an experience is its representational content (Byrne & Hilbert, 1997; Dretske, 1995; Harman, 1996; and Lycan, 1996). As Block (1999) points out: " the phenomenal character of experience is exhausted by such representational contents" (p. 39-40). In the next section, I will look at Block's arguments about this issue.

14.4 Block on Represenation and Inverted and Shifted Spectra

Block (1999a,b) has argued against the view that there is nothing experiential that goes beyond the representational content of experience, i.e. the claim that phenomenal character of experience is exhausted by representational contents. For example, the phenomenal character of an experience as of red consists in its representing something as red. Block (1999a) argues that representationism can be refuted by the concepts of the inverted and the shifted spectra.

14.5 Inverted Spectra

Block argues for the existence of qualia. He proposes that qualia are features of experience that go beyond the experience's representational, functional and cognitive features. He contrasts this view with representationism, which says that the phenomenal character of an experience of red consists in its representing something as red. In other words, the phenomenal character of experience is exhausted by representational contents. As Tye (1996a) puts it " qualia ain't in the head". In addition to Tye, this general view is strongly supported by Armstrong (1996a), Jackson (2001), Dretske (1995), Lycan (1996), Harman (1996). Block (1999a) has a striking view about qualia. He says:

> In my view, qualia could turn out to be, e.g., functional states. I think qualia are entities whose scientific essence is at present entirely unknown, and we cannot rule out a computational-functional theory of them. (p. 66).

Block (1999) argues that the inverted spectrum refutes representationism because it is a case of two people whose experiences are representationally alike in that they both report red, but they are phenomenally different .One experiences red and the other experiences green. Block points out that if phenomenal character is included in representational content as a sense component, then the inverted spectrum would not be a case of the same representational content but different phenomenal character. As Block argues the inverted pair would have experiences with different representational contents. However, Block stresses that:

> the representationists I'm after would never accept unreduced phenomenal characters as senses or as involving individuating senses. (p. 41).

They want a purely referential situation.

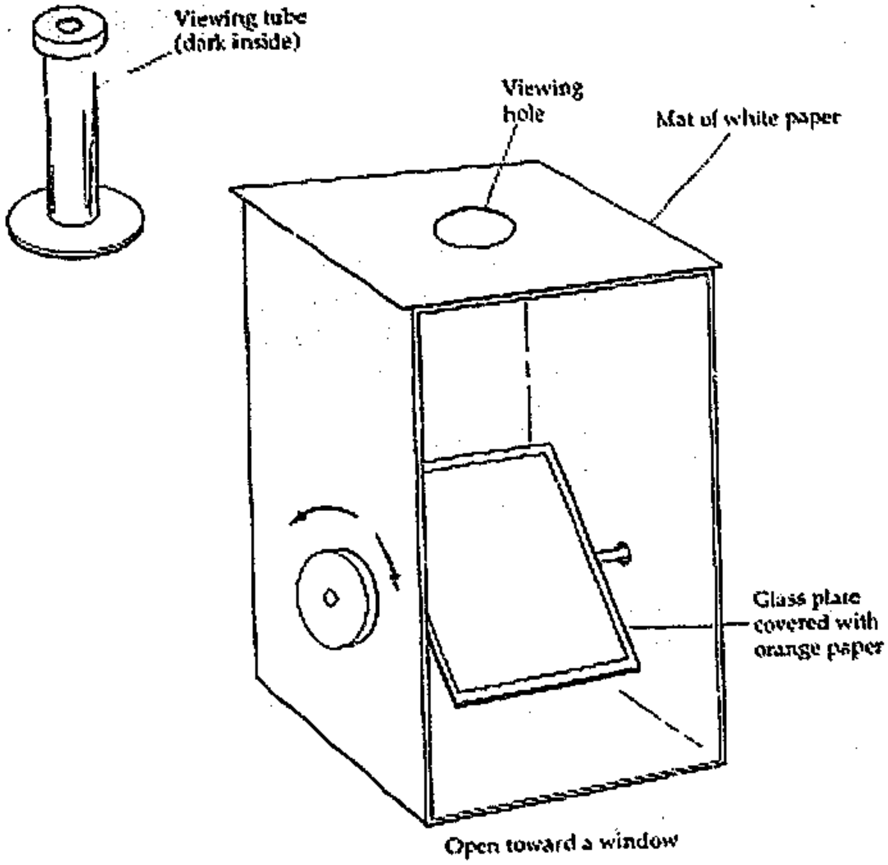
Block (1999) stresses that the inverted spectrum would only refute representationism, if the inversion had isomorphisms at the behavioural and functional levels. There have been a number of attempts to show a lack of isomorphism (Harrison, 1967,1986,1999; Hardin, 1988; Clark, 2000). Clark has proposed that the Bezolde-Brucke phenomenon could break the isomorphism. However, this effect only shows that red and green appear before blue and yellow with increasing light. This does not help with the most common version of inverted colour (i.e., when red and green are inverted and blue and yellow are inverted). Harrison's asymmetries involve difficulties with the language of colour and don't seem relevant to these two inversions. Hardin (1988) argues that there is an asymmetry as red and green are thought to be warm colours and blue and yellow are cool colours. This asymmetry is rather difficult to test with possible inversions.

The most difficult case of inversion to refute is when it is proposed that the person suffering the inversions has had the inversions since birth. However, they have learned to call red by the name red, even though they see green. Similar appropriate types of responses are given with blue-yellow inversion. Palmer (1999) has stressed the importance of isomorphism in the difficulty of detecting any inversion. However, Hilbert and Kalderon (2000) claim that it has not been possible to discover a satisfactory method to imagine symmetrical colour spaces. But they present no real evidence for this claim. It is an unusual claim as they do point to one asymmetry that is difficult for the non-detection of inversion. They point out that blue and yellow are asymmetrical with regard to brightness That is, yellow changes to brown when there is a reduction in brightness whereas blue remains blue, even though it gets darker.

I have carried out an experiment which allows one to quickly discovers the type of asymmetry that Byrne and Kalderon (2000) discuss. It allows one to determine whether humans are suffering from both red-green and blue-yellow inversions. I built some apparatus that was used 150 years ago by Hering (see Figure 20B). This apparatus is a box with a white top. There is a hole in the top in the middle of the white area. The box is open on one side, so that light can enter. There is a small board, which can be rotated. Small pieces of coloured paper can be attached to the board. The experiment depends on the asymmetry produced on colours when the level of light is reduced. This can be achieved by rotating the board with the attached colour, so that less light falls on the board. When this done to yellow the colour changes to brown. When this is done to blue, the colour gets darker but remains blue. Thus a person who has a blue-yellow inversion could be tested. Subjects would be tested with the box by looking through the hole. They would be asked to name the colour and to say whether the colour remains basically the same as the light hitting the board is reduced. This reduces the brightness contrast of the board compared with the white top. When presented with yellow, an inverted subject says blue when the maximum light was used. However, when the light is reduced, he does report a colour change for his

Figure 20 B

Hering's light box which enables one to vary the amount of light on a coloured paper by rotating a plate to which coloured paper can be attached. The paper can be viewed with or without a white surround by inserting a tube containing dark material. When relatively small amount of light is reflected toward the eye yellow and red appearing paper goes brown and green and blue paper go darker but don't change colour. (From Hurvich, 1981).


Viewing tube
(dark inside)
Viewing
hole
Mat of white paper
Glass plate
covered with
orange paper
Open toward a window

reported blue. When a blue stimulus is presented, the subject says yellow, but he keeps reporting yellow as the actual colour does not change from blue even though it gets darker. Philosophers with normal colour vision (as tested with Ishihara plates) reported appropriate colour changes under these conditions (i.e. yellow changed to brown and blue to dark blue). When the judgement was made at low light levels, a black tube with black material lining it's walls was placed in the hole. It could be seen that the brown reverted to yellow, showing that the change in colour is due the greater brightness of the white surround of the hole, relative to the brightness contrast of the yellow stimulus under reduced conditions. Thus a person with blue-yellow inversion would be detected by this colour change. When red and green were used, then red changed to a brown colour and green remained a dark green so this inversion was also detected. I think it is reasonable to conclude that these forms of human inversion would be detected by this experimental technique. Kaiser and Boynton (1996) say that:

> Other dark colours such as olive green and navy blue appear to be qualitatively more similar to their brighter counterparts than brown is to yellow and orange. (p. 46).

Thus for human beings an inverted spectrum of this form would not be damaging for representationism or for functional accounts of perception as this simple functional method allows the detection of the inverted colour.

I would like to stress that this result only applies to inversions in human beings. It still leaves open the possibility of undetectable inversions in other creatures. Shoemaker (1982) has commented that:

> Even if our color experience is not invertible, it seems obviously possible that there should be creature, otherwise very much like ourselves, whose color experience does have a structure that allows for such a mapping... creatures whose color experience is invertible. And the mere possibility of such creatures is sufficient to raise the philosophical problems the possibility of spectrum inversion has been seen as posing. (p. 367).

Cohen (1999) also argues in the same way. He says:

> functionalism must provide an analysis of the color experiences of any metaphysical possible creature who has them. For this reason,

functionalism is vulnerable to spectrum inversion not just between actual human beings, but between any two metaphysically possible creatures. (p. 950).

While I agree with the tenor of these remarks, I still would argue that detecting inversions in human beings is a step forward in applying functionalism and representationism to us. It is in keeping with the stress I want to lay of Kim's (1993) concept of local reduction in a species. I am more than happy to be species specific or chauvinistic in this

14.6 Shifted Spectra

However, Block (1999a) thinks he has another form of spectral change, which really refutes representationism in human beings. He calls this form "shifted spectra". His argument appeals to the fact that colour vision varies from one normal perceiver to another. Block (1999a) looks at several different types of evidence for this claim.

(1) He reports that two normal people chosen at random will differ in " long" cone peak sensitivity by 1-2 nm with a standard deviation of 1-2 nm. He points out that this is a considerable difference as the "long" and " middle " wave cones only differ in peak sensitivities by about 25 nm.

(2) There are a number of specific genetic divisions in peak sensitivities in the population. There is a 51.5% / 48.5% split in the male population of two types of long wave cones that differ by 5-7 nm . However, women have smaller numbers in the two extreme categories but have a much larger number of another cone type in between. As a result a match on the Raleigh test the female match most frequently occurs where no male matches (Neitz et al., 1993) In the Raleigh test subjects are asked to make two halves of a screen match in colour.

(3) Matches also vary with age due to differences in macular pigmentation (Neitz et al., 1993).

(4) Also races with different skin pigmentation will differ in macular pigmentation and thus will differ in matching.

(5) Block (1999a) cites a study of the spectral location of unique green (Hardin, 1988) of 50 normal subjects. Their settings ranged over 27 nm. Block concludes:

that if we take a chip that any one subject in this experiment takes as being unique green, most of the others will see it as slightly bluish or yellowish. (p. 43).

Block (1999a) concludes from all of this that:

> if two experiences can have the same representational content (e.g. unique green) but different phenomenal character so representationism is wrong. (p. 46-47.

I would like to present some evidence that might reduce the strength of these claims.

Firstly, Sivik (1997) and Hard and Sivik (1986) have looked at different forms of methods for the matching of colours. Sivik (1997) points out that if two identical surfaces are first presented adjacent to each other, as in the Raleigh test, and then one is varied until a JND can be seen, the number of different colours can range up to 10 million.

He then reports an important observation:

> To arrive at this large number of distinguishable colors requires that the colors be juxtaposed. If we move them apart by even a few centimeters, the two color surfaces, which when juxtaposed are seen as clearly dissimilar, immediately appear identical. If we hold color samples even further apart from each other rather large color differences are necessary if we are to see surfaces as different. Suddenly the number of perceptually distinct colors has dropped to a couple of thousand, or less. (Sivik, 1997, p. 161).

This important result would appear to have strong implications for Block's (1999a) arguments about matching. It would appear that large color differences are necessary for subjects to see narural surfaces as different. This would suggest that the Raleigh matches that Block evokes to support his spectra shift, might not be active in the real world outside the laboratory. That is, it might not be the general case of similar representations with different phenomenal characters. In support of this claim I will now look at some work with unique hues.

Mollon and Jordan (1997) reported a study of unique green with 97 normal male observers (Figure 20C). Like the study quoted above, there was a considerable range of settings for unique green. They did report one striking correlate of unique green, They found a significant relationship between ratings of the lightness of each subject's iris and the unique green. Subjects with light irises have unique green settings that lie at shorter wavelengths than do subjects with medium or dark irises.

Mollon and Jordan (1997) bring out some important implications from this result. They point out that the lightness of the iris is often taken to be an index of the level of pigmentation present in the fundus of the eye, behind and between the photoreceptors. The absorption of light transmitted through the iris and sclera, and of light scattered within the eye, is greatest at short wavelengths and so pigmentation of the fundus will modify the spectral composition of the light actually absorbed in the photoreceptors.

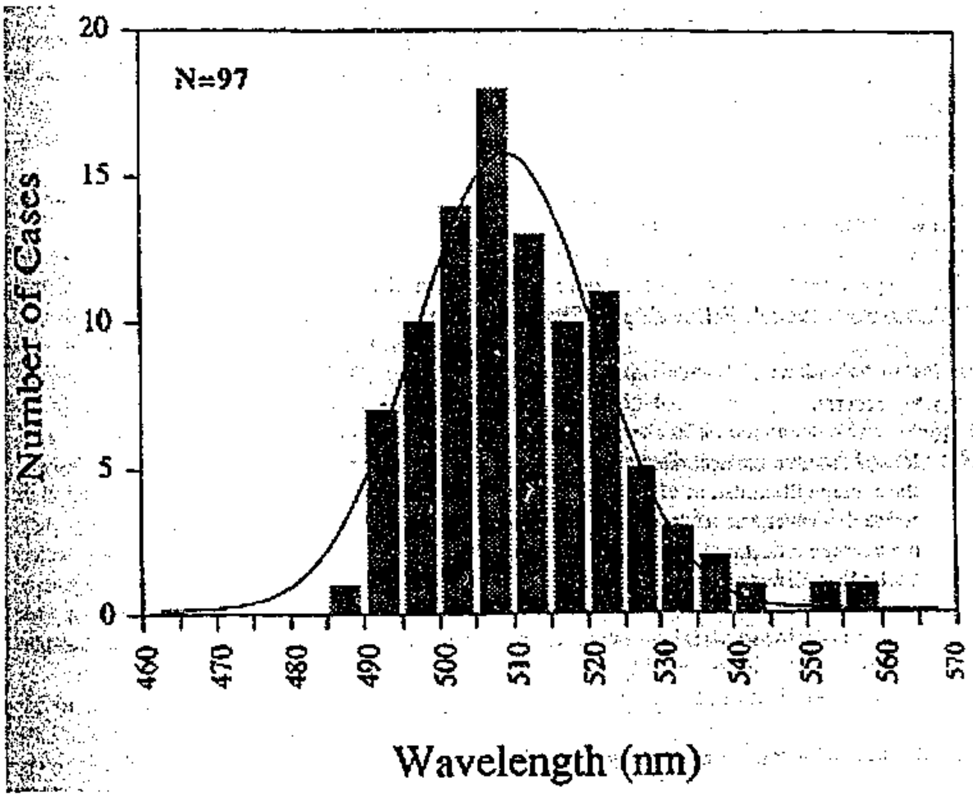
Mollon and Jordan (1997) go on to say;

> However, the stimuli commonly used to establish unique hues are near- monochromatic ones, and ocular pigmentation should not modify the ratios of quantum catches that a given wavelength produces in the different cone types. Yet suppose that the spectral position of unique green does not correspond to a genetically fixed set of cone signals, but instead depends on an observer's interaction with broad-band stimuli in the real world. Consider two observers, one with light pigmentation, one with heavy, but with identical photopigments. Suppose these observers agree that a certain leaf is neither glaucous nor yellowish. The ratios of quantum catches that the leaf produces in the cones must differ from the corresponding ratios for the other observer. If these two observers agree on unique green in the real world, then they ought to differ when we bring them into the laboratory and confront them with monochromatic lights. For they will need different monochromatic lights to imitate the cone ratios. (p. 390).

Thus most of the observers in Block's example would see identical unique greens in the real world, especially if Sivik's work is taken into account. Mollon and Jordan (1997) go on to say:

FIGURE 20 C

Distribution of wavelength set as unique green by 97 normal male observers. The mean value is 511 nm with a standard deviation of 13 nm. The normal distribution with the same mean and standard deviation is shown as a solid line overlaid on the histogram. (From Jordan and Mollon, 1997).


N=97
Number of Cases
Wavelength (nm)
0
5
10
15
20
460
470
480
490
500
510
520
530
540
550
560
570

This approach to unique hues makes a clear prediction. The variance between observers should be less when they judge surface colours than when they judge spectral colours. (p. 390).

They then discuss the famous case of Dr Sulzer, which was reported by Donders (1884). The Raleigh match for Dr Sulzer's left eye lay at the protan end of the normal distribution whereas the match for his right eye lay at the deutan end. When tested for unique yellow, Dr Sulzer chose 577 nm for unique yellow with his left eye and 587 nm with his right eye, However, there was no difference between his eyes when asked to choose unique yellow in a set of graded papers differing in steps of one JND.

These results would suggest that Block's stress on unique hues having different values for most observers is not necessarily supported. The work of both Mollon and Jordan (1997) and Sivik (1997) would indicate that most observers would see unique hues as having virtually identical wavelengths or at least ones that differed very much less than their Raleigh matches. Thus it would not be a case of identical representations and different phenomenal characters and representationism would not be refuted.

14.7 Conclusions about representationism

In the early part of this chapter, I examined Tye's presentation of representationism and I suggested that it was not an adequate account. I would still support the representation account of perception. However, I would prefer to put it in Armstrong's (1968, 1979) terms that perception is a case of belief. As Jackson (2002) also claims in supporting Armstrong's views, when talking about the representational state. He argues that belief is the representational state par excellence. I regard Armstrong's (1979) arguments in support of a belief account of perception against a qualia account to be decisive, as I set out in Chapter 14.3. .

CHAPTER 15.0

In this Chapter, I will look at two theorists who specifically argue that there are no colours. I have placed them in the non-physical property of non-physical entities / elimination box of Table 3

15.1 Maund's Theory of Colour

Maund (2000) has an interesting summary of the state of play in the field of colour. He says that:

> Despite much thought, over thousands of years, by philosophers and scientists, however, we seem little closer now to an agreed account of color than we ever were. The disagreement is reflected in the fact that some theorists believe colors to be perceiver-relative, e.g., dispositions or powers to induce experiences of a certain kind, or to appear in certain ways to observers of a certain kind. Others take them to be objective, physical properties of objects. Among the latter group, some take these properties to be physical microstructures, while others regard colors as sui generis irreducible properties of physical bodies, and yet others take them to be dispositional properties to affect light. Finally, there are even some who deny that there are colors in the world at all: there are none of the colors, it is claimed, that we naturally and normally and unreflectingly attribute to objects. (p. 1).

Maund places himself in this last category.

Maund (1994) has written an important book on colour in the context of an error theory of colour. There are several major theses that he puts forward:

(1) He argues that we have a natural or naive concept of colour. It is the concept of colour we employ in describing the colours we perceive in everyday life before there is philosophical or scientific enquiry. In this natural view, colours are intrinsic, objective, non-dispositional, non-relational properties of physical objects and of the surfaces of physical objects.

(2) The view of colour in this natural concept is one of direct realism. Colours appear to us; we are able to see them directly and they play a causal role in producing visual experiences of colour. Colours are identified by means of their characteristic appearances, much like Jackson's putative view. But colours are also useful to us. They have important aesthetic and emotional effects and they function as signs for objects of interest, e.g., sorting and classifying things by their colour.

(3) Despite these arguments, Maund claims that as a contingent fact that nothing is actually coloured. No object exemplifies any of the colours that this natural concept specifies. In Maund's terms colour is a virtual property. This is an extreme error theory which asserts color nihilism.

It is worth looking at Maund's account of virtual properties in some detail. He says:

> It turns out, however, that the natural concept of colour contains certain false claims. There are in fact no objects which have colours as normally conceived. Virtual colours are intrinsic, non-relational properties of physical objects.... not withstanding the error thesis, it does not follow that the natural concept does not have a valuable role to play.... for many purposes, it is as if the objects had such colours. The point is that even if colour is a virtual property, there is a significant and important dispositional property: the power to induce sensory representations which represent objects as having (virtual) colours. (Maund, 1994, p. 104).

As noted above, Maund (1994, 2000) has proposed that colour is a virtual property. This is an error theory of colour. He argues that it:

> consists of the claim that we perceive physical objects as having colours that they do not have. (Maund, 1994, p. 25).

Maund argues that colours are of philosophical interest for two kinds of reason. First, colours comprise such a large portion of our social, personal and epistemological lives. Second, there are considerable philosophical problems in trying to fit colours into accounts of metaphysics, epistemology and science. He says that:

> Not surprisingly, these two kinds of reasons are related. The fact that colours are significant in their own right, makes more pressing the philosophical problems of fitting them into more general metaphysical and epistemological frameworks. (Maund, 2000, p. 1).

Maund's arguments against an objective account of colour follows most of the ones already specified in this thesis. He lays great stress on the difficulties presented by metamers and opponent processes and unique hues (Maund, 1994, p.141-142). He says that " There are no physical properties and relationships that govern the ordering " (p. 142) of systems such as the Munsell or the CIE. He essentially says that any objective account of colour does not match the psychophysical account, such as the 3-dimensional account provided by the CIE figure (pp. 141-145). He points to the Bezolde-Brücke phenomema as emphasized by Hurvich (1981), in which changes in brightness lead to changes in colour, which are not picked up by the CIE system.

Instead, Maund puts forward an error theory of colour, in which colour is a virtual property. It is difficult to understand what Maund means by a virtual property. In one place, Maund asserts that:

> Virtual colours are of course 'objective' colours: they are objective properties that do not exist, just as phlogiston and caloric are objective natural kinds that do not exist. (Maund, 1994, p. 160).

I find this concept of 'objective' as very hard to understand. If something does not exist how can it be an objective property? Phlogiston and caloric might have been proposed as a natural kind, but they have been refuted and falsified. Surely, Maund does not want the concept of a vitual property to be a falsified or refuted one?

Maund (1994) has a most unusual extension to his theory about colour, which he describes as the pluralist framework. He argues that there are three concepts underlying colour. He says that:

> The functions of the virtual-colour concept can be taken over by the dispositional concept, the phenomenal concept and the objective concept. Objects with virtual colours are allegedly (a) objects with certain causal powers, (b) objects which appear a certain way and (c) objects whose appearances have certain qualitative character. Very roughly, physical colour takes over the causal role, dispositional colour takes over the appearance role and phenomenal colour takes over the qualitative character. Although the pluralist account makes room for an objectivist concept of colour, it does not make it mandatory.....I argue that there is no successful account of colour which dispenses with the need for a dispositional concept, one which in turn requires both virtual colours and phenomenal colour. (Maund, 1994, p. 115).

I find these arguments difficult to follow, because earlier in his book, Maund puts forward arguments about virtual colour that are difficult to reconcile with these three concepts. He says:

> What is this intial concept of being yellow? I maintain that it is a concept of a virtual property. What this means is that it is a concept which in actual fact no physical object has. It is an intensional property, a property of a physical surface, objective in the sense that the surface has it independently of whether anyone is looking....What I am supposing is that we can have concepts of individual objects that do not exist...Banquo's ghost, the man on the moon, the philosopher's stone-- and of substances that do not exist-- caloric, phlogiston--so we can have concepts of properties that do not exist. These I am calling concepts of virtual properties. Colour, thought of as a property of a physical surface, is just such a one. Colour as a physical property is a virtual property. There are no instances of physical objects that have such a physical property. (Maund, 1994, p. 75).

Yet, he wants to argue above that physical colour takes over a causal role. How can something that does not exist have a causal role?

Maund has some interesting things to say about virtual colours and their relationship with the concept of qualia. Firstly, he believes quite strongly in qualia, He says:

> For many, the existence of qualia is simply self-evident. Only a madman would deny them. Or, to put it more accurately, for me to deny that I have them I would have to be mad. For those who believe in qualia, it seems that the best evidence for them is one's own experience. (Maund, 1994, p. 175-176).

Maund, however, puts forward three arguments for qualia. One is the Inverted Spectrum Argument. Second is the Knowledge argument of Jackson. The third is what he calls the Phenomenological Argument. I have answered the first argument earlier in this thesis, in that the inverted spectrum can be detected in a functional way (see Chapter 14.6). Thus the argument that qualia can occur without any reference to external stimuli does not look so compelling.

Maund (1994) says that the Phenomenological argument:

> is based on making sense of perceptual experience from the first-person point of view. It reflects an attempt to make sense of the phenomenology of experience. It is I hold, not only the most powerful of the arguments for qualia, but it lies at the heart of other arguments, including variations of the classical ' argument from illusion'. (p. 176).

Maund is a strong qualia-defender, but he has an unusual account of qualia. He puts forward two concepts of qualia. One he describes as phenomenal qualia and the other he calls open-qualia. Maund says that:

> qualia are the qualitative features in virtue of having which objects (tokens) qualitatively resemble each other and differ from each other. We ought to define a wider term that leaves it open whether or not these qualitative features are features of phenomenal objects or experiences, or alternatively of physical events or states...... Let us use the term 'open-qualia' to apply to those features which are so defined as to leave open whether instantations of them are physical or phenomenal. (p. 43).

This concept of open-qualia is difficult to understand as Maund explains it. For example, he asserts that:

> One of the features that constitute the virtual-colour concept is that colours are open-qualia. No physical features of physical bodies are in fact open-qualia. However, our sensory representations which represent virtual colours have features which are qualia. That is, they are phenomenal qualia. But, of course, being phenomenal qualia they are also open-qualia. It is because we experience these phenomenal qualia in a three-dimensional space and on the basis of this experience judge that, say, this watermelon is green or that sunset is red and so on, that our concepts of green, red, brown, etc., contain the quale element. (Maund, 1994, p 45).

Maund is saying that we experience these phenomenal qualia in a three dimensional space, such as the CIE space or the Munsell space, but that these spaces cannot be physical spaces, therefore they have to be phenomenal spaces. He thinks that they cannot be physical spaces because of the concepts of opponent processes and unique hues etc., which we have already suggested that they might not apply in this way. Frank Jackson (1995) in a review of Maund's book takes issue with this claim. He points out that:

> we who identify colours with the physical properties that do the right kind of causing of colour experiences must show that these physical properties stand in similarity and difference relations that mirror those in the three dimensional colour array. I think we need to ask in what sense does looking red represent objects as having a property more like the property orange represents them as having than does looking green; in what sense, that is, is orange as represented in experience more like red as represented in experience than it is like green as represented in experience? A clearly wrong answer would be to say that it is somehow 'more' true or more obvious that orange is a different colour from green than that it is a different colour from red. It is certainly true and completely obvious both that red is different from orange and that red is different from green. One attractive answer to our question borrows from behavioural psychology and

analyses the needed sense in terms of JND's (just noticeable differences). It takes more JND's to get from orange of a given saturation to green of the same saturation than to get to red of the same saturation. But--and here is my query... in that sense the physical properties do stand in the right similarity relationships. They induce the relevant behavioural relationships. More generally, the point is that if we can somehow analytically reconstruct the three-dimensional array in terms of suitably scaled JND's, then it is hard to see how the properties of the array could refute an identity theory of colour. (p. 244).

Jackson does not emphasize that such a three dimensional scale has already been constructed (Kaiser and Boynton, 1995) (Figure 21), which would allow one to analytically reconstruct the three dimensional array in terms of suitably scaled JND's. A set of 424 commercially available colour specimens was developed called the OSA (Optical Society of America) Uniform Color Scales samples. The samples are arranged in an array along the vertical axis from black to white (L of Figure21). This is orthogonal to two chromatic axes, one of which runs roughly from red to green (g in Figure 21). The other runs from blue to yellow (j in Figure 21). The arrangement of these colours is intended to cause the perceptual distance between each colour and its nearest neighbours to be constant throughout an ordered matrix of colour samples. The system provides a set of equally spaced colour samples whose arrangement in physical space is intended to define a three-dimensional domain in which linear distances imply the same number of just-noticeable colour steps regardless of the starting point or the direction traversed. Kaiser and Boynton (1996) say that the OSA system comes closer to meeting this objective than any colour-order system that has been developed. Kaiser and Boynton (1996) show some data that reveal the number of JND's between colours (Figure 22). It is on the scale of the OSA and it clearly shows more JND's going from red to green than from red to orange (Figure 22). This evidence not only supports the physicalist leanings of this thesis in suggesting an identity, but it suggests that the virtual colour explanation is not necessary.

It is interesting to note that Maund regards his virtual theory as being nihilistic about colour. He asserts that " the theory of virtual colours would be a

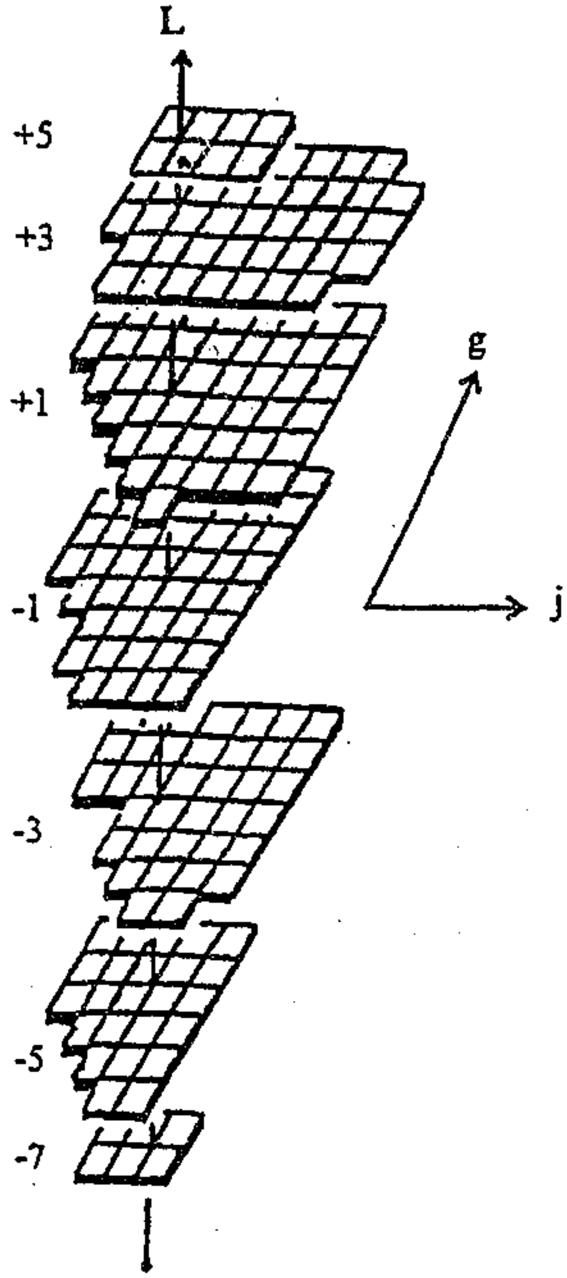


Figure 21: Arrangement of the OSA colours. The lightness axis L runs from near black at the bottom to near white at the top, with a neutral gray sample at each of the even-numbered lightness levels, which have been left off the diagram for clarity. At each lightness level, there are two chromatic axes, labeled j and g, which are perpendicular to each other and to the lightness axis. Each of the 424 colour chips of the system is intended to be equidistant from its nearest neighbours, of which there are 12, except for the outermost shell of colours. (From Kaiser & Boynton,1996.)

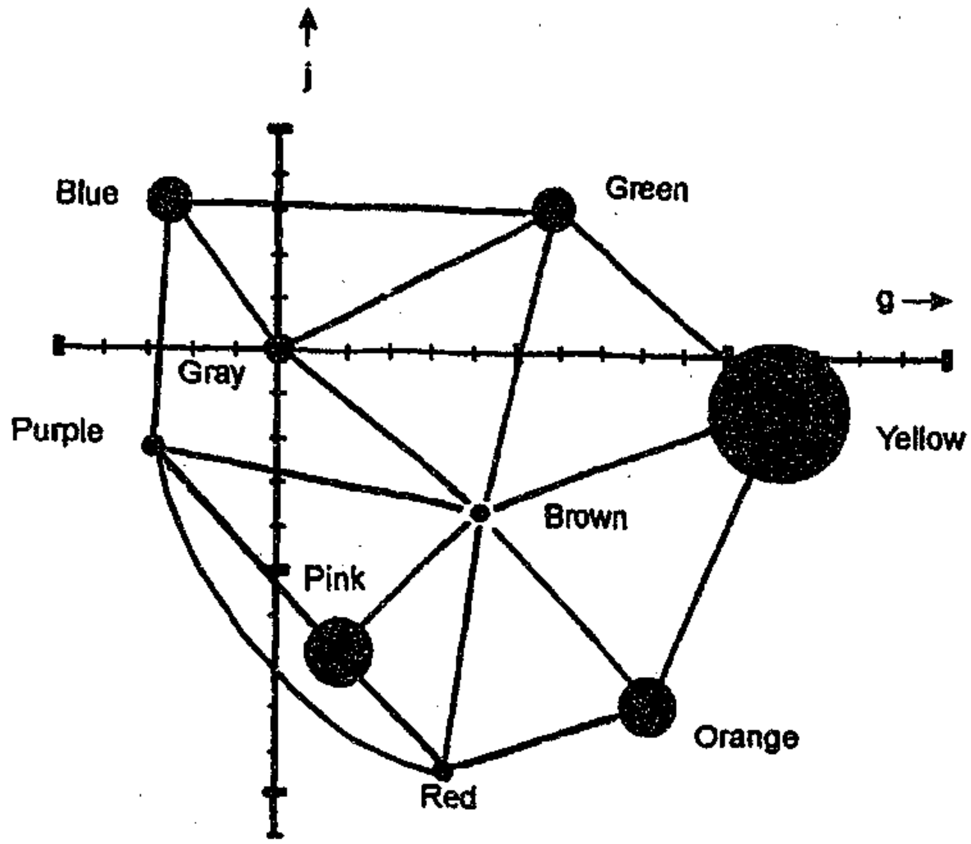


Figure 22: Location of centroids for the basic colours projected to a common chromatic plane of the OSA Uniform Colour Scales system. The j and g axes are marked off in steps of unit OSA distance. The centroids of colours are not actually located in the same plane; the size of the symbols has been varied to suggest their location in the third dimension (the higher the lightness level, the larger the symbol). (From Kaiser & Boynton,1996).

form of colour nihilism " (Maund, 1994, p 103). That is, there are neither physical nor subjective forms of colour. It would appear that the JND's evidence would refute such a nihilistic position. In this context and unlike other subjective theorists. Maund does not argue for projection mechanism, whereas Campbell (1993) argues that all subjectivists use projection. He says " It needs to be stressed that this account does not require colours, either phenomenal or virtual, to be projected into space" (p. 172) This would appear to require great accuracy about location in the dispositional part of his pluralistic theory. Overall, I feel that Maund's theory of colour is rather incoherent and is not supported by either the data supporting the PE / W theory or the JND's data. It depends strongly on the processes about colour which I have discussed and shown to be not so challenging that they lead to subjectivisms, such as Maund' theory.

15.2 Landesman's theory of colour

Landesman (1989,1993) has put forward a somewhat similar theory about colour to that of Maund. The major difference is that Landesman does not take a nihilstic view of colour, instead he describes his view as a skeptical one He says:

> I have formulated color skepticism as the claim that nothing exemplifies or has any color. Another possible formulation is that colors do not exist, that there is no such thing as color. However, these formulations are not equivalent, for although the latter entails the former, the former does not entail the latter. With respect to a universal, to an entity that is capable of being exemplified, it is one thing to say nothing exemplifies it and another to say that there is no such thing. (Landesman, 1989, p. 105).

Landesman (1989) comes to an amazingly strong conclusion. He says that:

> since all our color perceptions are hallucinatory, we have no conception at all of what veridical color perception would be like. If there were a veridical color perception, it would be no different at all from one that is hallucinatory . (p. 115).

He then says that:

all visual perception includes a hallucinatory phase, and since we all share in it, the hallucination is collective. There is nothing absurd or unintelligble in the idea of a collective hallucination. For what makes a set of experiences hallucinatory is not that it disagrees with established consensus, but that it disagrees with the way things are. (Landesman, 1989, p. 115).

Landesman comes to this conclusion by a set of arguments against both a dispositional and a microstate explanation of colour. Landesman (1989) looks at dispositions as what he calls a pure power analysis. This is based on Locke's account of secondary qualities. He lists 6 features of Locke's account of an individual perceiver's veridical sense awareness of a red body:

(1) there exists the body sensed as well as the corpuscles that compose it.

(2) there are the primary qualities of the individual corpuscles and of the body taken as a whole.

(3) there is the sense experience in the mind of the perceiver, what Locke variously calls a sensation or an idea.

(4) there is the quality red insofar as it occurs in the sensation or idea...the apparent red or perceived red

(5) there is the power or disposition that the body has in virtue of its primary qualities to cause sensations of red in perceivers. This is red as a secondary quality, or dispositional red. The system of primary qualities in the red object that underlies the disposition. What Landesman calls its microstates.

(6) there is the actual causal transaction between the body and the perceiver in which the power is actualized.

Landesman (1993) takes issue with Locke's view of colour as a secondary quality. He looks at the concept of a primary quality. He argues that this concept depends on the state of physical theory. He asserts that on the basis of modern science there is no reason to suppose that any individual atom or corpuscle has a colour. He bases this on the fact that colour has no causal role in modern physics. He says that:

> that a tomato looks red, for instance, does not depend on the colors of atoms of which the tomato is composed; it does depend upon the effects of the atoms reflected from its surface upon the human eye. (p. 85).

Apart from the strange assertion that atoms are reflected into the eye, this is a general position maintained by Locke (1975). Locke (1975, II, vii, p 16) also argued that if one should prick one's finger with a pin and feel sharp pain, then there is no need to propose that there is a pain in the pin to explain why my encounter with it caused me pain. The pain is a subjective effect of the pin upon my flesh, not an objective feature of the pin or of any of the atoms that compose it. He then asserts that apparent colour is the same case as pain. That this object looks red to me here and now is an effect of the interaction with my visual organs. Landesman (1993) says that:

> It is absurd to ascribe the color I see or am directly conscious of to the object or its atoms as it would be to ascribe pain to the pin or its atoms. (p. 85).

Landesman (1993) argues that if one took two colourless atoms and placed them side by side, then there would be no reason that the entity which is the sum of both atoms would have any colour if they individually lacked it. He then argues that adding individual atoms would produce no colour until a certain size is reached and then the group would be visible. But the Landesman says that even here there would be no need to suppose that any colour is a real property of the object. It is simply a consequence of the effects of reflected light. While it can be agreed that it is unlikely that individual atoms are coloured, it has been emphasized in this thesis that colour (or photon-energy / wavelength) has important interactions at the atomic level. As Nassau (1980) said:

> color is a visible (and even conspicuous) manifestation of some of the subtle effects that determine the structure of matter. (p. 106).

Of course, Nassau (1980) like most colour scientists argues that:

> The perception of color is a subjective experience...perceived color is merely the eye's measure and the

brain's interpretation of the dominant wavelength or frequency or energy of a light wave. (p. 106).

This is, of course, a dispositionalist argument, suggesting that nature in itself, independently of the brain-mind system cannot produce apparent colour. Landesman (1989) argues that there is a problem here in that colour is not dispositional, because we mistakenly identify apparent red, which is occurrent, with red as a secondary quality. Landesman (1989) argues that:

> When we ascribe a color to a body, we must distinguish two beliefs that may both be involved in the thought underlying our ascription. If I say, ' That is red. ' I believe first that that really does have the color red, and second that the red it has is an occurrent quality. Locke never thought of challenging beliefs of the first sort. He wanted to present a theory of perception according to which most of our secondary quality ascriptions are true. But given his argument that secondary qualities cannot be occurrent, he was required to interpret them as dispositional.....and thus reject as false beliefs of the second sort..... in order to preserve he truth of beliefs of the first sort. We are now in a position to understand that there is another alternative: secondary qualities are occurrent but nothing has them. Or, more accurately, secondary qualities would occur if they were exemplified, but nothing exemplifies them. (p. 25).

Landseman also argues against dispositions with an argument somewhat similar to Jackson's (1996) argument. He says that:

> One piece of evidence against the dispositional view is that the names for colors as they occur in natural language are not dispositional terms. Compare the difference between 'light blue' and ' fragile. The latter means ' can easily be broken.' That it designates a dispositional quality can be known by reflecting on what it means, whereas ' light blue' is no more dispositional in meaning than are 'square' and ' round.' As far as we can discover by reflecting on meaning, colors are no more dispositional than are shapes. (Landesman, 1989, pp. 26-27).

I think Landesman is trying to say what Jackson claims that we infer fragility but see colours and shapes.

Landesman argues against an objective theory of colour, largely on the grounds that colours and microstates are different properties. For example he argues that colours are capable of being seen and microproperties are not capable of being seen. Therefore, they express incompatible properties and thus cannot be predicated of the same entity. This argument does not appear to support his skeptical view as colours could still exist or be exemplified. Landesman (1989) then puts forward a rather strange argument for skepticism. He says that:

> we know how to cause people to see an uninterrupted expanse of color on a sheet of paper by covering the paper with colored dots. If the dots are small enough and sufficiently close together. (p. 52).

He then argues that:

> it is a mistake to claim that the expanse of color really is the same as the bunch of dots, for this implies, incorrectly, that there actually exists a smooth expanse of color. It only seems that way. Instead of supporting the implausible claim that colors are microstates, the case of the colored dots, when correctly described as the illusion it is, supports the view that colors do not really exist. (p. 53).

But surely, even if we concede that the smooth expanse is an illusion, that does not mean that the small coloured dots do not exist! They could still be colours not hallucinations as Landesmam argues. In fact, we could take Jackson's (1996) proposal that there are two groups of colours present, e.g. that of the expanse and that of the dots.

Overall, I hold that Landesman has not made out a good case for skepticism about colour. He fails to give any detailed analysis of the colour literature, such as the work of Hardin or Smart. He does not directly mention the various colour phenomena that I have discussed. He indirectly talks about metamers without naming them. He says that the same yellow appearance can be produced by various mixtures of light waves. He does not even support the projection concept so often used by subjectivists. He says of colour that:

> The illusion does not consist in our unconsciously 'projecting' color qualities onto objects that fail to exemplify them, for there are no exemplified qualities to project. (Landesman, 1989, p. 109).

His main argument against reductive explanations is that colour and microstates have different properties. This would hardly count if an identity could be established in the manner we have shown for AI's.

CHAPTER 16.0

16.1 Revelation and Transparency

Johnston (1992), in an paper, which I cited earlier, argues that the philosophy of colour is one of those " genial areas of inquiry in which the main competing positions are each in their own way perfectly true." (p. 221). As an example, Johnston says that as between:

> those who say that the external world is colored and those who say that the external world is not colored, the judicious choice is to agree with both. Ever so inclusively speaking the external world is not colored. More or less inclusively speaking the external world is colored. (p. 221).

Johnston (1992) argues that there are a core of beliefs about colours which are the basis of inclusively speaking. They include: paradigms, explanation, unity, perceptual availability, and revelation. These beliefs were set out in detail in Chapter 12.2.

Revelation is the most difficult belief for the proposition that the external world is coloured as Johnston argues that revelation and explanation cannot be true together. The content of Revelation was put forward by Russell (1912) as:

> the particular shade of colour that I am seeing.......may have many things to be said about it......But such statements, though they make me know truths about colour, do not make me know the colour itself better than I did before: so far as concerns knowledge of the colour itself, as opposed to knowledge of truths about it. I know the colour perfectly and completely when I see it and no further knowledge of it itself is even theoretically possible. (p. 47).

Other philosophers (Strawson, 1989; Harding, 1991; Campbell, 1993; McGinn, 1996) also support the concept of revelation or transparency. Strawson (1989) says that:

color words are words for properties which are of such a kind that their whole and essential nature as properties can be and is fully revealed in sensory-quality experience given only the qualitative character that that experience has. (p. 224).

I will give again a quotation from Johnston (1992) that puts it quite strongly that:

given what we know from the psychophysics of perception it follows that Revelation and Explanation cannot be true together. For when it comes to the external explanatory causes of our color experience, psychophysics has narrowed down the options. Those causes are either non-dispositional microphysical properties, light-dispositions (reflectance or Edwin Land's designator dispositions or something of that sort) or psychological dispositions (dispositions to appear colored) with microphysical or light-dispositional bases. Explanation therefore tells us that we must look among these properties if we are to find the colors. Revelation tells us that the natures of the colors are, in Gregory Harding's useful idiom, laid bare in visual experience. The nature of canary yellow is supposed to be fully revealed by visual experience so that once one has seen canary yellow there is no more to know about the way canary yellow is. Further investigation and experience simply tells us what further things have the property and how that property might be contingently related to other properties. (p. 139-140).

David Lewis (1997) argues that the concept of revelation presents problems for materialism about colours. He says that:

The only remaining difficulty is that the doctrine is false. At any rate, it is false for colour experiences (and colours themselves). At any rate, it is false by materialist lights....... and we have pledged ourselves non-negotiably to materialism. The essence of colour experience is not at all simple, not at all ineffable, not at all easily known. Probably it is a matter of neural firing patterns, but if not that, something equally esoteric. Likewise for the essences of the colours themselves. The doctrine of revelation is tailor-made to solve our problem. But we materialists must dismiss this 'solution' as a useless piece of wishful thinking. (p. 338).

Lewis gives no indication of how the doctrine is false. It is the aim of this chapter to demonstrate this falsity.

Johnston (1992) argues for a dispositional theory (DT) of colour in that a major advantage of a dispositional theory of colour over a primary quality theory (PQT) is that it gives enough to revelation to avoid skeptical worries that any PQT necessarily engenders. He argues that:

> Vision can be a mode of revelation of the nature of visual-response dispositions. It cannot be a mode of revelation of the properties that the Primary Quality Theorist identifies with the colors. Since we are inevitably in the business of refiguring our inconsistent color concepts, we should make the revision , which allows us to secure an important cognitive value......the value of acquaintance with those salient, striking and ubiquitous features that are the colors.
>
> The point here is not simply that the Primary Quality Account does not satisfy even a qualified form of Revelation. What is more crucial is that as a result, the account does not provide for something we very much value: acquaintance with colors. The ultimate defect of the Primary Quality View is therefore a practical one. From the point of view of what we might call the ethics of perception; the Secondary Quality Account is to be preferred. It provides for acquaintance with the colors. (p. 258).

Jackson (1996) argues that this misunderstands the nature of the issue between PQTs and DTs. Jackson (1996) says that there is:

> no deep metaphysical dispute between primary quality theorists and dispositionalists. The dispute is over whether the disposition to look colored or the primary quality bases of those dispositions should be tagged as the colors; the dispute is ultimately over the distribution of names among putative candidates. And how we answer this labelling question can have no cognitive or epistemic significance. (pp. 211-212).

McGinn (1996) also favours a revelation and dispositional account of colours, but like Jackson he does not favour the classical DT account put forward by Johnston. McGinn claims that there are four difficulties for DT with each on its own sufficient to discomfort the theory in its classic version.

(1) The first difficulty is that dispositions are not visible properties of things in the way that colours are, thus the two cannot be identical. This is a difficulty first raised by Jackson & Pargetter (1987), but no acknowledgement of this is given by McGinn. Jackson & Pargetter argue that colour is the categorical basis of the disposition, not the disposition itself. They say that we perceive colour but infer dispositions such as fragility. McGinn (1996) contrasts colour with the disposition of solubility. He says:

> you do not, in the direct-object sense, see things under dispositional descriptions. Solubility is a property you infer, rather than one that it is directly revealed to you..... colors are given, while dispositions are posited. (p. 540).

McGinn does not go on to argue that colours are categorical properties, as we shall see.

(2) The second difficulty concerns the structure of perceived colour. McGinn argues that according to DT, colours consist in relations between objects and perceivers and these relations are dyadic, bringing in the perceiver and the conditions of perception. McGinn says this misrepresents the phenomenology of colour perception, since we see color as having a simple, monadic, local property of the object's surface. Thus he says that:

> No relation to perceivers enters into how the color appears; the color is perceived as wholly on the object, not as something straddling the gap between it and the perceiver. (p. 542).

(3) The third difficulty is that DT analyses colours by reference to experiences of say red, so that these experiences enter into the nature of the property: they are what redness is a disposition to produce. McGinn argues that DT is a double dispositional theory. He says that:

> two entities and their dispositions are in question here: the external object of sight and the mind with which that object interacts. And just as the object has its dispositions in virtue of its intrinsic physical properties, so the mind will have its dispositions in virtue of (presumably) the physical properties of the perceiver's nervous system. DT is thus a double dispositional theory. (p. 539).

It is interesting, as I said earlier, that Johnston (1996) in a recent paper on colour has put forward a similar double dispositional theory. He says:

> The same perceptual experience is as much a manifestation of my disposition to see the apple as red as it is a manifestation of the apple's disposition to look red to me. (p. 197).

McGinn then argues that if there is a double disposition and if colours are visible, then so must both dispositions be visible. But:

> one of these pertains to minds, so we have it unacceptably, that minds are visible. The truth is that when an object looks red to me, no mind looks any way to me-- nor could it. So minds and their states cannot enter into the constitution of color properties, given that these properties are visible. Colors are visibilia par excellence, but experiences are not even possible objects of perception. Again, DT has to say that we fail to perceive colors as they are. (p. 543).

Thus McGinn argues that colors can't be analysed by DT by reference to experiences, thus leaving revelation of colours as showing what colours are.

(4) The fourth difficulty involves the circularity of the notion that a disposition to look red is the essence of redness. This regress argument was evolved by Boghossian & Velleman (1989) and set out in Chapter 12.3.1, e.g. red, the property that objects are seen as having when they look red is a disposition to appear red under standard conditions. But, red expresses the same property on both sides of this definition, so the account is circular.

Because of these difficulties, McGinn has proposed a new type of dispositional theory for colour vision. He argues that the four problems stem from the thesis that colours can be identified with dispositions-- that they are reducible to them. McGinn argues that identity and reduction are not the only relations that can have a role with colour, He proposes that the weaker notion of supervenience is doing the work. He puts forward the notion that colour supervenes on dispositions (supervenience dispositional theory, SDT). He says that:

> The basis of color is indeed a disposition to appear, but what appears is not the disposition itself but rather the color property that supervenes upon it. Thus, the disposition does the ontological work, while not getting the phenomenology of color perception wrong. The content of visual experience is fixed by the unreduced color properties, with the grounding dispositions lying outside of such contents. The trick is to let the dispositions control the colors, via supervenience, while not collapsing the colors into dispositions. (p. 547).

McGinn wonders whether SDT should be still called a dispositional theory. He says that the new theory (SDT).

> on balance, that it should not be so called, since it explicitly rejects the claim that colors are dispositions..... I propose that the new theory be labelled _Impressionism about color. The label is appropriate for two reasons: first, the theory ties colors to sensory impressions, in the traditional way; second, it insists that the nature of color properties be approached by way of the content of color experience. Impressionism makes color ascriptions not only dependent upon how objects are disposed to look; it also holds that the nature of color is revealed [my emphasis] in how color objects look. (p. 547).

The main issue is how McGinn relates this revelation to supervenience? McGinn puts forward an unusual and novel relationship between revelation and supervenience. He says that:

> The answer nay be that it violates a set of deeply rooted ontological assumptions about the kinds of properties there can be, to the effect that all (empirical) properties should be either mental or physical or some combination of the two. On the classic DT, this dualistic assumption

is respected, since colors are taken to be constructions from mental and physical properties. But the revised impressionist theory implicitly rejects such a dualism: colors, for impressionism, form a distinct family of properties, not reducible to the psychophysical upon which they supervene.......despite their dependence on lower-level properties, the colors are in an ontological class of their own, not assimilable to anything else.......to the old question, 'are colors mental or physical, subjective or objective?', we must answer, 'Neither: they constitute a third category, just as real as, but distinct from, mental and physical properties'. (McGinn, p. 548).

This is obviously an extraordinarily strong version of revelation: colours can't be reduced to physical properties as they are on a different ontological level in that:

> colors are, after all, properties of physical objects. What we must accept is that it is just not true that every property of a physical object is either physical or mental: colors are a straight counterexample to that claim. (p. 549).

McGinn says that:

> one consequence of this is that physicalism would not be vindicated merely by providing a reduction of mental states like sensing something red, since even if that state were physically reducible it would not follow that redness itself can be reduced to a physical property. Redness might indeed be supervenient on wholly physical properties of both the external object and the perceiver's nervous system, but it will not thereby be physical-- even if sensations of red are as physical as you could wish. (p. 549).

This strong role of revelation has been pushed even further by Johnston (1996) in a paper entitled "Is the external world visible?' Johnston argues that revelation does not allow us to see the external world. All we can do is see the contents of our experiences. I will repeat my previous quotation of what he says to remind us of his extraordinary strong statement:

> To see involves having the natures of visible properties revealed by a causal process, but this is just what no causal process actually does. The originally unbelievable conclusion now follows: we cannot see color, because our visual experiences as of the colors of things do not reveal [my emphasis] to us what the colors of the external causes of our experience are like. But if we do not see color, we do not see color difference, and if we do not see color difference, we see neither edges nor colored areas, we do not see surfaces and if we do not see surfaces, we do not see anything in the material world. Our visual experience is then just ' a false imaginary glare', simply an arbitrary medium in which the material world is mapped for the purposes of intentional action. The characteristic pleasure of seeing, the pleasure of having the nature of visible properties and visible things revealed to us, is a false pleasure. The promise of vision appears totally fraudulent. What is driving the general argument about perception and the specific argument about color seems to be a certain standard of acquaintance with or revelation of [my emphasis] the natures of perceptible properties, in effect the standard that Russell arrived at by taking visual perceptions on its own terms. (p. 191).

We can see from both McGinn and Johnston why Jackson (1996) thought that strict revelation made the primary quality view of colour false. He says:

> thus, if it is part of folk theory that the experience of color reveals in itself the nature of color, that color is transparent in this sense, the primary property view must be false. (p. 210).

As I mentioned earlier, Jackson (1996) puts forward three reasons for denying this form of revelation. I think that Jackson's three arguments go some way to refuting Johnston's original notion of revelation, but I believe that more is needed to rebut the stronger versions of revelation put forward by McGinn and Johnston (1996). To achieve this, I wish to discuss some experiments on colour we have carried out (Webster et al, 1992)

One of the intuitive attractions of revelation about colour is Russell's claim that other truths about colours would not make one know the colour itself better than one did before. For example, if it could be established that colour was reducible to the photon energy / wavelength property of photons and their interaction with electrons (Webster, 2000b), would this tell me more about the colour green than I would be getting from simply experiencing it? I would know a truth about the colour green, but it would still appear as a simple, monadic, local property of an object's surface. What would be really revealing would be to show that two cases of apparently similar simple, monadic, local properties (e.g. green) were really quite different. Before outlining the experiments that achieved this, some theoretical background is necessary.

There are two dominant theories of early visual processing: feature detection (or edge and bar) theory and linear spatial-frequency theory. Kelly (1976) extended linear spatial-frequency analysis to stimuli with two-dimensional profiles, such as checkerboards. Kelly (1976) showed that the two-dimensional Fourier transform of a checkerboard pattern is the convolution of a bar-grating spectrum with a similar one rotated by 90^0. Kelly (1976) showed that for two types of checkerboards, a square 1/1 checkerboard (SCB) and a diagonal 1/1 checkerboard (DCB), there were four pairs of fundamental frequency components in the theoretical spatial-frequency plane (Figure 23 b & c). Each component is oriented at 45^0 from the edges of the checks. This means that there is no Fourier energy parallel to the edges of the checkerboards; rather the energy is located at the orientations of the fundamental and harmonic frequencies of the checkerboard spectrum. The frequency of the fundamental components was $\sqrt{2} \times F$, where F is the frequency of the two square-wave gratings. The components were located at 45^0-225^0 and 135^0-315^0 for an SCB and at 0^0-180^0 and 90^0-270^0 for a DCB. (Figure 23 b & c). Kelly (1976) also showed that the other harmonics are widely distributed throughout the spatial-frequency plane. For each checkerboard, there are four pairs of third harmonics with a frequency of $\sqrt{10} \times F$, located at various positions (Figure 23 b & c). There are also four pairs of fifth harmonics at various orientations and with a frequency of $\sqrt{26} \times F$ (Figure 23 b & c). Figure 24 shows the Fourier components for a number of checkerboards and for a plaid pattern and a grating. The plaid pattern has edges like the checkerboards but unlike them the Fourier components line up with the edges. In Figure 24A, the orientations and the

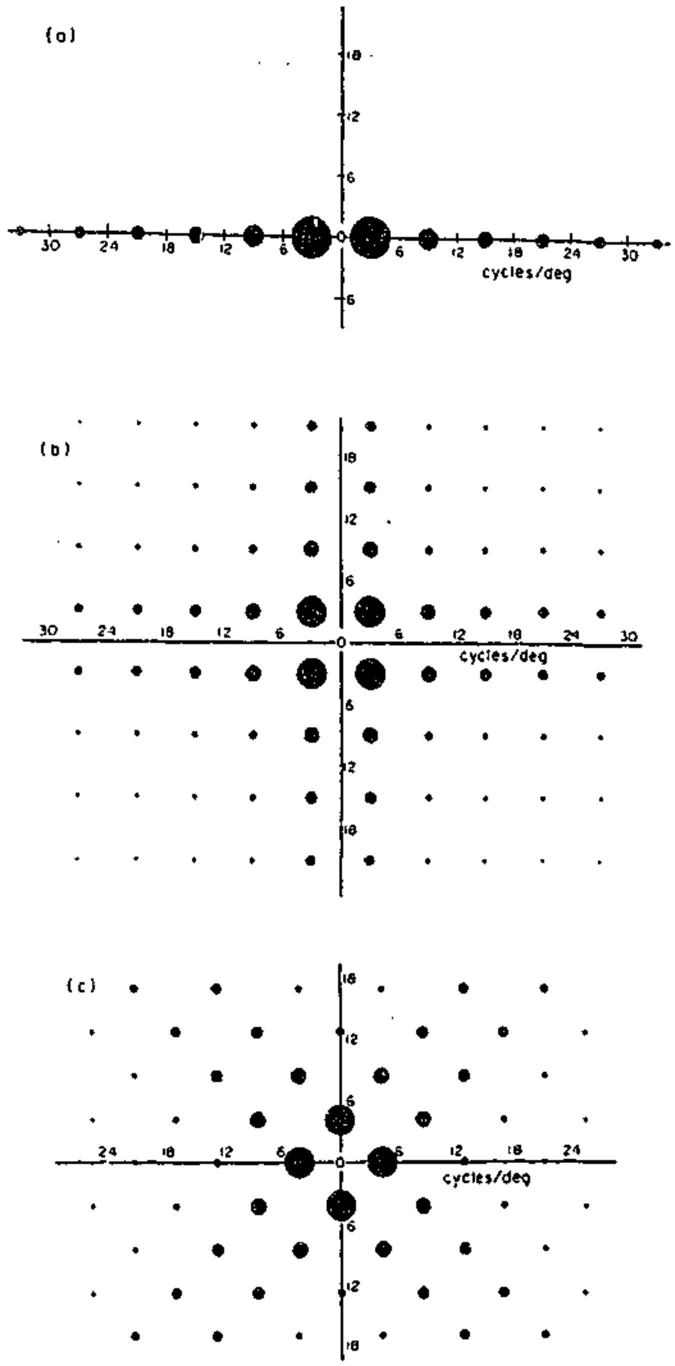


Figure 23: Two-dimensional Fourier spectra ot three types of periodic spatial patterns. (a) square-wave grating of 3 c/deg, (b) a SCB of 3 c/deg leading to a fundamental frequency of 4.2 c/deg at 45°from the edges, (c) spectrum of the same checkerboard rotated 45° to DCB position. Although the edges are now located obliquely, the fundamental components are now on the horizontal and vertical meridians. The magnitudes of the Fourier components are represented by the areas of the filled circles. Higher harmonics are widely distributed throughout the spatial frequency plane. (from Kelly, 1976).

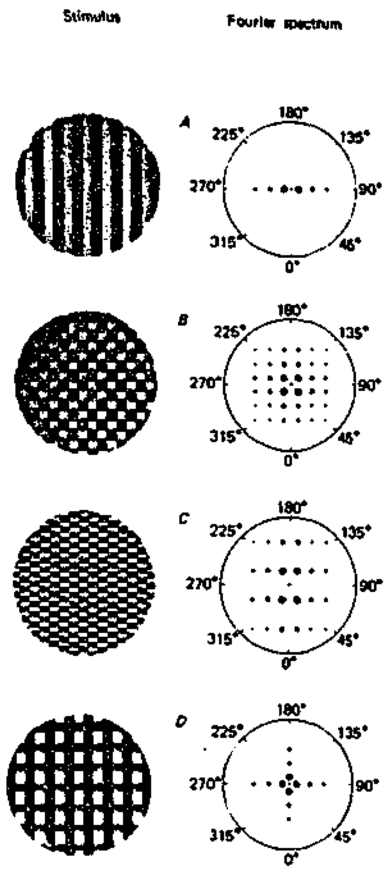


Figure 24: Stimulus patterns and their two-dimensional Fourier spectra. In the left column are photographs of the oscilloscope displays of each stimulus. The right column depicts the two-dimensional spectra (out only to the fifth harmonic compared with picture 23) corresponding to each of the photographs on the left. Frequency is represented on the radial dimension, orientation on the angular dimension, and the areas of the filled circles represents the magnitudes of the Fourier components.. A: a square-wave grating, B: a 1/1 (checkheight/ check width) square checkerboard (SCB),C: a 0.5/1 SCB, D: a plaid pattern. (From DeValois et al., 1979).

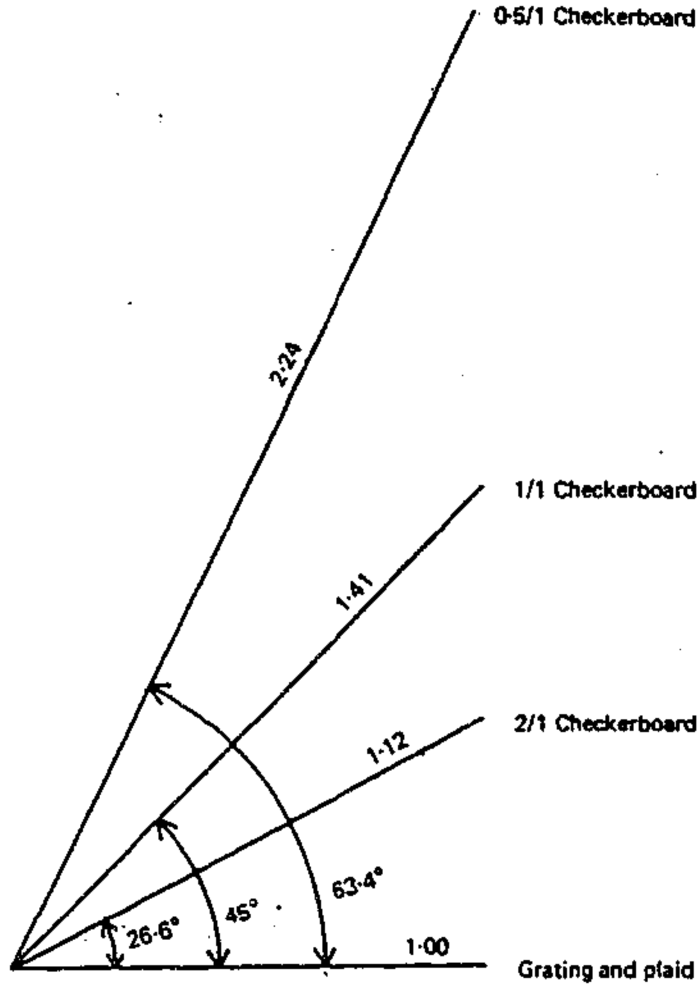


FIGURE 24: Orientations and fundamental frequency of checkerboards and a plaid based on a horizontal square wave grating of 1c/deg. A 1/1 SCB has a fundamental frequency of $\sqrt{2} \times 1 = 1.41$ c/deg. (from DeValois et al., 1979

frequencies of the fundamentals of a number of checkerboards are shown. Also the orientations and frequencies of gratings and plaids are shown.

It was decided to test the notion of the location of energy by using the well known McCollough (1965) effect. The McCollough effect produces a contingent after-effect by adapting coloured, oriented gratings for a period of time and then testing with achromatic gratings. For example, adapting with red and black vertical gratings and green and black horizontal gratings produces a green after-effect on a black and white vertical gratings and a red after-effect on black and white horizontal gratings. These effects are long lasting and contingent on both colour and orientation. They are not afterimages as turning the head through 45^0 removes the after-effect and turning the head through 90^0 reverses the colour seen on the two test gratings (Day et al., 1992). It was predicted that adapting with coloured checkerboards and testing with sine-wave gratings oriented at the locations of the edges and the harmonics and fundamentals, there would only be after-effects at the energy locations indicated by Kelly (1976). That is, there would be no colour energy located at the edges.

After adaptation with 1/1 SCB's of 4 cycles per degree alternated with a blank field every 10 seconds for 10 minutes, significant after-effects were produced on gratings at the orientation of the checkerboard fundamental and the third harmonics, but not on gratings located at the orientation of the edges. The one exception was a small effect located at 90^0 for the third harmonic (Figure 26). A four-way ANOVA with repeated measures was carried out on the test grating data. There was a significant main effect between the gratings at the orientation of the spatial-frequency components and those oriented with the edges. That is, the fundamental and harmonics of the checkerboard produced significant effects compared with the edges. Statistical t tests of individual conditions confirmed this effect (Figure 26). The after-effects were measured by a colour cancellation technique. When a subject reported a red after-effect, for example, he / she would add green until the colour was cancelled to white. This measure was related linearly to steps on the CIE colour plane (Webster et al., 1988), thus giving an objective measure of the after-effect. Adaptation with a 1/1 SCB of low spatial frequency (0.8 cycles per degree) produced some interesting effects. Significant

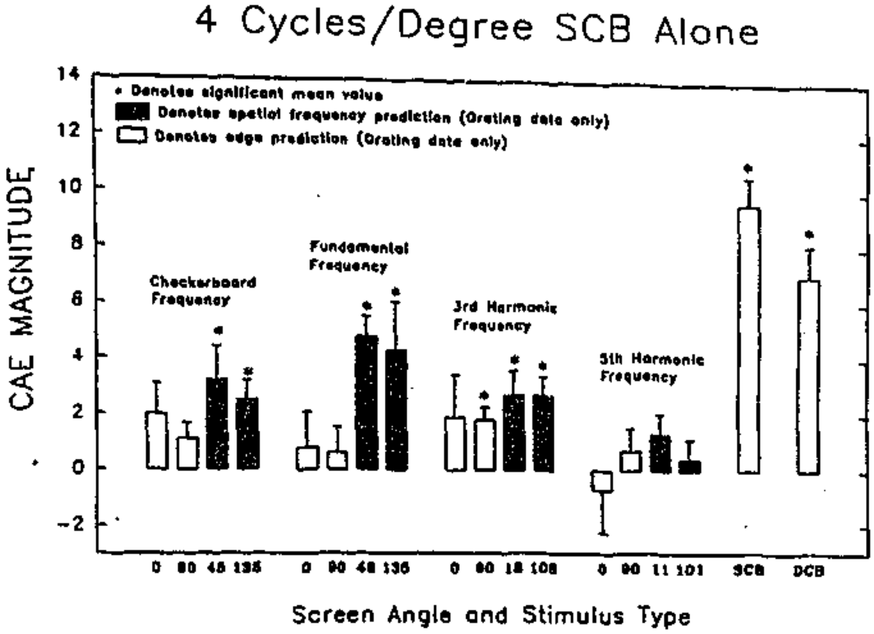


FIGURE 26 : Mean contingent aftereffect magnitude (CAE) after adaptation to a 1/1 SCB of 4c/deg, plotted as a function of oscilloscope screen angle for test gratings and stimulus type (SCB and DCB). The scores for the test gratings are grouped according to the frequency components of the checkerboard : checkerboard frequency, fundamental frequency, third harmonic frequency, and fifth harmonic frequency. Hatched bars denote screen angles at which CAE's for test gratings would be predicted by spatial-frequency theory. Unfilled bars denote screen angles at which edge-detector theory would predict CAE's. Error bars represent the standard error of the mean. (from Webster et al.,1992)

after-effects were produced on gratings located at the fundamental and the third harmonic. But a significant after-effect was also produced on a grating of the checkerboard frequency located at the edges. This result indicates that there is both an edge and a spatial frequency mechanism operating with low spatial-frequency checkerboards. (Figure 27). Similar effects were generated by adapting DCB checkerboards of similar frequencies (Webster et al., 1992). It is important to note that significant after-effects were produced in all experiments on both types of achromatic checkerboards, when only one checkerboard was adapted (Figures 26& 27). This result indicates strong effects of spatial frequency, since adaptation of a grating will not produce an after-effect on gratings oriented with edges at 45^0 from hose of the adapting grating, as shown by the head turning mentioned above.

In some unpublished experiments, we showed that adaptation of a plaid pattern produced a McCollough effect only on its edges and not on the orientations of a checkerboard Fourier components.

These psychophysical data are supported by neurophysiological studies carried out by De Valois et al. (1979). They showed that cells in primate and cat V1 cortex would fire to edges of gratings, but would not fire to edges of checkerboards. They would fire, however, if the orientations of the fundamental and the third harmonic of the checkerboard were appropriately oriented over the cell's receptive field. This showed that there was no energy at the orientation of the edges of the checkerboard, but instead energy was located at the orientation of the spatial-frequency components. In Figure 28, the responses of a cell show that a grating and a plaid are responded to at the orientation of their edges, but a checkerboard responses are shifted 45^0 to either side.

Let us now look at the implications of these data for revelation and transparency of colour vision. As Jackson (1996) says:

> a number of philosophers have indeed suggested that it is part of the folk theory of color that color experience is transparent in the sense of *revealing* [my emphasis] the essential nature of color. (p. 210).

However, it would seem that the above experiments don't support this argument. With the checkerboards, the plaids and the sine-wave gratings, we have

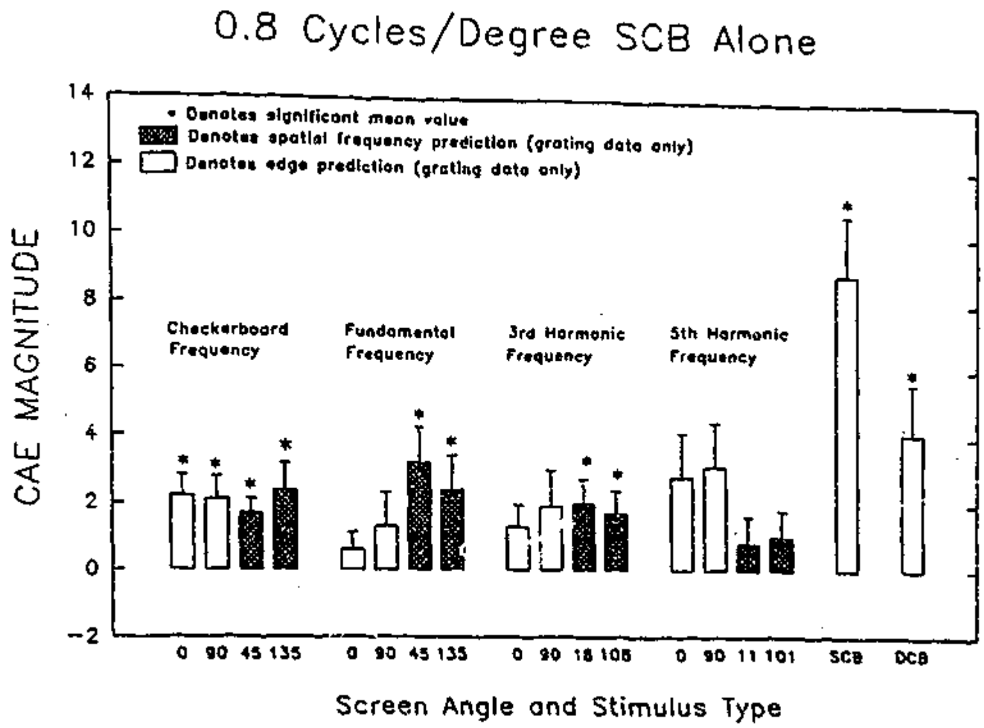
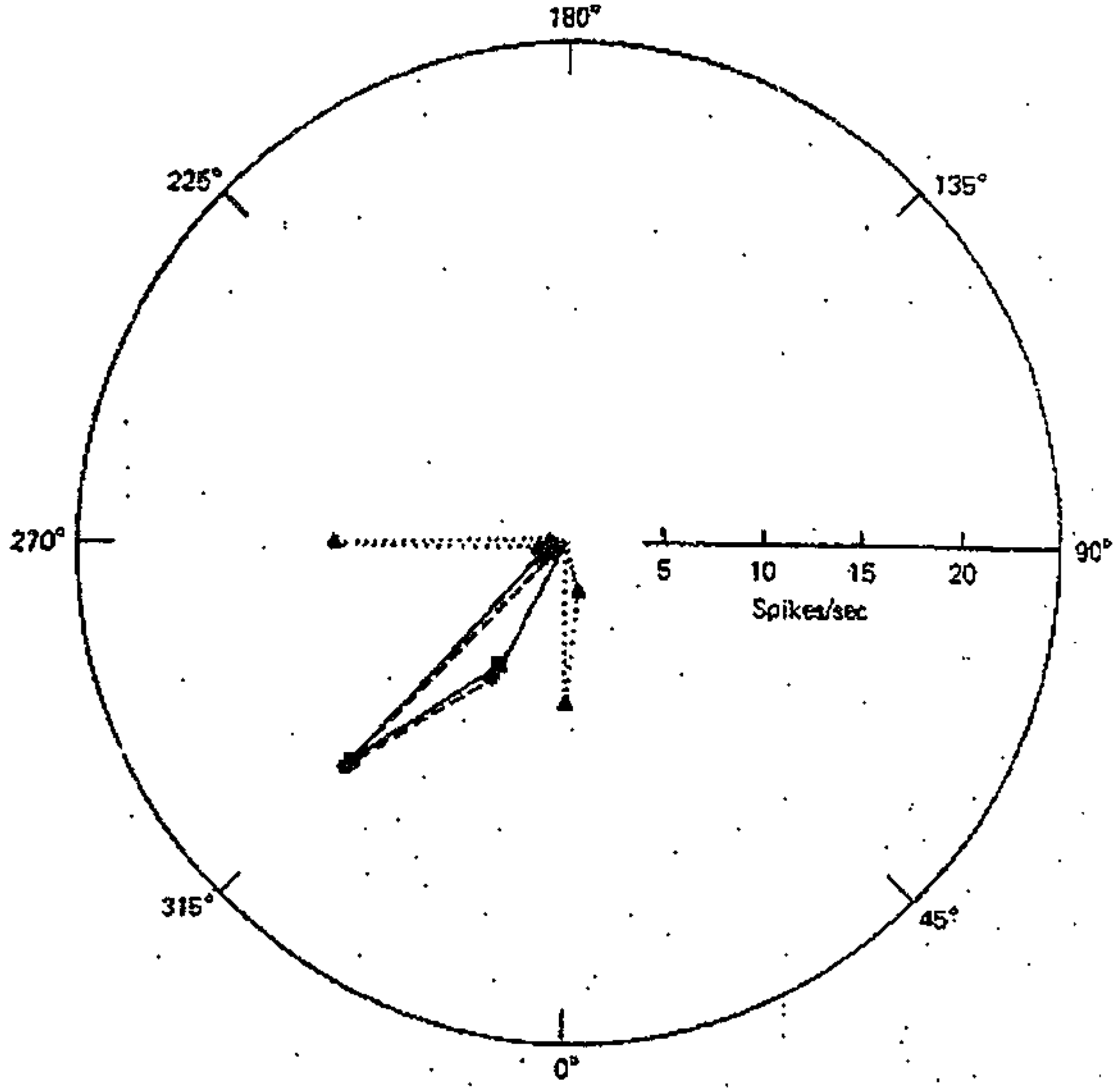


FIGURE 27: Mean contingent aftereffect magnitude (CAE) after adaptation to a 1/1 SCB of o.8 c/deg, plotted as a function of oscilloscope screen angle for test gratings and stimulus type (SCB and DCB). The scores for the test gratings are grouped according to the frequency components of the checkerboard : checkerboard frequency, fundamental frequency, third harmonic frequency, and fifth harmonic frequency. Hatched bars denote screen angles at which CAE's for test gratings would be predicted by spatial-frequency theory. Unfilled bars denote screen angles at which edge-detector theory would predict CAE's. Error bars represent the standard error of the mean. (from Webster et al.,1992)

Figure 28: Responses of a cat simple cell to a grating (■-----■), a 1/1 checkerboard (▲ ---- ▲) and a plaid pattern (●-----●). The responses are plotted with respect to the orientations of the edges in the patterns. Note that the grating and the plaid pattern yield the same orientation tuning, while the response lobes for the checkerboard are shifted 45 ° to either side of their edges. (DeValois et al.,1979).


180°
225°
135°
270°
90°
5
10
15
20
Spikes/sec
315°
45°
0°

what appears to be simple, identical examples of colour. For example, the colour green of the after-effect on either an SCB or a DCB or a plaid appears to be identical, simple, monadic colours. Yet the psychophysical data indicate that energy or photons are coming off the checkerboards at different orientations. The green photons of an SCB are coming off at 45^0 and at 135^0, whereas they are coming off at 0^0 and 90^0 from a DCB. The photons from the plaid are coming off aligned with the edges. Other photons are coming off at the different orientations of the harmonic components of each checkerboard. Thus just viewing the green does not reveal the essential nature of the colour. In the case of the low frequency checkerboards, we have an even more complex situation, as colour energy is located on both the edges and the spatial-frequency components. These Fourier processes appear to be additional to the fifteen different causes of colour outlined by Nassau (1983). Nassau argued that colour is produced by the interaction of photons with electrons. The Fourier process occurs after this level of interaction. However, Nassau's mechanisms also present problems for revelation.

Armstrong, in Armstrong & Malcolm (1984), advocates a causal theory of mind. He says:

> It is true that the causal theory of mind does lead naturally to a materialist theory of mind. For suppose that we consider all the outward physical behaviour of human beings, and other higher animals, which we take to be mind-betokening. In the light of our current knowledge, it seems quite likely that the sole causes of this behaviour are external stimuli together with internal physiological processes in particular physiological processes in the central nervous system, but if we accept this premiss on grounds of general scientific plausibility, and also accept the causal theory of mind, the mental must in fact be physiological. (pp.57-158).

These spatial-frequency data clearly indicate a causal theory of colour in a two-dimensional system, such as checkerboards. It would appear that the mental event of perceiving colour depends on causal external stimuli, the spatial-frequency oriented photons, and on the physiological processes in the central nervous system, e.g. the colour and orientation cells in V1 cortex acting as spatial frequency filters in responding to the orientation of the energy of the harmonic components. This system would appear to indicate that colour is identical with these causal processes, rather than supervening on these processes in the way McGinn (1996) suggests. It is difficult on the basis of these data to see colour as being different ontologically from both the physical and the neurophysiological processes and from mental processes, as McGinn's impressionism theory advocates. It would appear that colour can be given a stronger relation than supervenience and his support of revelation in this form is not warranted.

The evidence reported here does not support Johnston's (1996) more recent exposition of revelation. Johnston says that:

> The other problem of the external world is acquaintance. The problem of how, given the nature of information transmission, we could be acquainted with the nature of any of the properties of external things represented by our experience. The nature of any signal received is partly a product of the thing sending the signal and partly a product of the signal receiver. It seems that we cannot separate out the contribution to our experience of our own sensibility from the contribution to our experience of the objects sensed. (p.187).

It would appear that we can separate out the contribution of our sensibility (V1 cells) and our experience of the objects sensed (spatial-frequency analysis). We can take our perceptual experimental experiences to reveal the true natures of external things, which can't be revealed by simple perceptions.

It is argued on the basis of these experimental data that a stronger relationship than supervenience holds in these cases. It could be argued that this is a case of reduction to a mind/ brain identity of the McCollough effect and spatial-frequency components in V1. I stressed earlier that Schaffer (1970) has argued for three necessary conditions to allow reduction to a mind/brain identity and the three conditions are jointly sufficient. The three conditions are that the two terms of an identity must (1) be located in the one place; (2) must occur at the same time, and

(3) the presence of one must be an (empirically) necessary condition for the presence of the other.

The first condition requires some detailed argument. I would like to make the case that the McCollough effect is localized in the simple cells of V1 cortex. DeValois et al., (1979) has clearly shown that cells in primate V1 are sensitive to the spatial frequency components of checkerboards. They describe them as being two-dimensional spatial-frequency filters. Michael (1978) has stressed that the McCollough effect only occurs monocularly. He points out that simple cells:

> are the only known neurons in the monkey's visual pathway which are monocular, color sensitive and orientation selective. Thus they may be the neural basis of the McCollough effect. (p. 1248).

This means that the effect is not occurring more centrally as most central cells are binocular. It won't be occurring more peripherally than V1 as there are no orientation sensitive cells there. Michael (1978) also adapted primate simple V1 cells with red and black gratings and tested them with achromatic gratings. He found that they responded like the McCollough effect by indicating green. Overall, this evidence is not as strong as that presented in Chapter 13.5 in which an area was reversibly blocked to show the location of an AI, but it would seem to point strongly to the necessary location being in V1.

Another feature of the McCollough effect is the long lasting time course of the effect, which suggests some long-term type of synaptic change. There is evidence that long-term synaptic change can occur in V1. Long-term potentiation has been widely accepted as a neuronal substrate of long-term synaptic change after prolonged use. (Brown et al., 1988; Gustafsson and Wigstrom, 1988). There is evidence that long-term potentiation and depression are present in visual cortex (Berry et al., 1989; Komatsu et al., 1988; Artola et al., 1990). In a relevant experiment, Creutzfeldt and Heggelund (1975) found that adapting cats for 1 hour twice a day to vertical gratings over a period of 2 weeks led to a decrease in the number of V1 cells responding to vertical gratings. Thus indicating that long-term changes can be produced by use. I would contend that Shaffer's first condition of the same location is reasonably met by the data on V1.

The second condition appears to be met as the McCollough effect occurs at the same time that the spatial- frequency components in the checkerboards occur to stimulate spatial-frequency filters. It should be stressed that with plaid patterns no McCollough effects occur to the spatial-frequency components oriented away from the edges. The third condition occurs because the presence of the spatial-frequency component at its particular orientation is a necessary condition for the activation of the spatial-frequency filters and the presence of the McCollough effect in checkerboards, as shown again by the plaids. Overall, I think that Shaffer's conditions for an identity have been met.

In general, it is thought that the psychoneural identity theory of Smart (1959) had been refuted by the multiple realizability arguments of Putnam (1980), which inspired functionalism. Putnam's basic point is that any psychological event-type can be physically realized in endlessly diverse ways. Thus it was unlikely to obtain a general type-type mind-brain reduction. This argument applies, of course, to supervenient explanations. Horgan (1993) has proposed a stronger form of supervenience-- superdupervenience-- a form of supervenience that gaurantees that supervenience properties are nothing over and above their physicalistically acceptable base properties. He proposes a strong restraint in that:

> any genuinely materialistic metaphysics should countenance inter-level supervenience connections only if they are explainable in a materialistically acceptable way, and should countenance ontological inter-level supervenience relations only if they are robustly explainable in a materialistically acceptable way. (p. 563).

However, Horgan argues that superdupervenience does not apply to type-type identity for 'what-it's-like' mental properties such as qualia. He bases this argument on the explanatory gap argument of Levine (1983). Horgan says:

> (appeals to type/type identity seem only to shift the mystery, rather than eliminating it: why should any given physical or neurobiological property be identical to a particular what-it's-like property...e.g., the property experiencing phenomenal redness .... rather than some other property or to none at all?). This ' explanatory gap'

problem is well described, specifically in relation to type-identity treatments of qualia, by Levine (1983). (p. 580).

I regard the Fourier data presented here as overcoming the explanatory gap as it is based both on a physical analysis of the visual stimulus (Kelly's, 1976) analysis) and the psychophysical data, in conjunction with the neurophysiological data showing the existence of spatial frequency filters that are both colour and orientation sensitive. Thus one can predict the phenomenal properties, such as spatial frequency sensitivity and orientation of the coloured after-effects and show that the physical and psychophysical conditions are necessary and sufficient for the effect. A similar identity, overcoming the explanatory gap, was shown for afterimage. It should be stressed that these two identities do not establish an overall identity between all mental properties and neural events. Rather, they should be regarded as what Kim describes as local reductions in the same species. Kim (1993) argues that:

> This is reduction in a full-blown sense, except it is limited to individuals sharing a certain physical-biological structure. I believe 'local reductions' of this sort are the rule rather than the exception in all science, not just psychology. In any case, this is a plausible picture of what in fact goes on in neurobiology, physiological psychology, cognitive neuroscience, etc. And it seems to me that any robust physicalist must expect and demand the possibility of local reductions of psychology just in this sense. (pp. 274-275).

Although both examples of identity overcoming a small proportion of explanatory gaps are important, there is one aspect of each which needs further analysis. This is the issue of colour itself, apart from its role in afterimages and coloured after-effects. Levine (1983) states that:

> let's consider again what it is to see green and red. The physical story involves talk about various wavelengths detectable by the retina, and the receptors and processors that discriminate among them. Let's call the physical story for seeing red "R" and the physical story for seeing green "G". My claim is this. when we consider the qualitative character of our visual experience when

looking at ripe McIntosh apples, as opposed to looking at ripe cucumbers, the difference is not explained by appeal to G and R. For R doesn't really explain why I have the one kind of qualitative experience...the kind I have when looking at McIntosh apples...and not the other. As evidence for this, note that it seems just as easy to imagine G as it is to imagine R underlying the qualitative experience that is in fact associated with R. The reverse, of course, also seems quite imaginable. (pp. 357-358).

This is, of course, the classical inverted spectrum argument. This argument has had a long run in the philosophical literature (Lycan, 1973; Shoemaker, 1982; Levine, 1988; Tye, 1996a; Chalmers, 1996), but there is evidence that refutes it in the case of yellow and blue and possibly in the case of red and green. (see Chapter 14.0).

One of the problems for the inversion scenario is what happens to the existing physiological structure. In the case of red/green inversion, it would seem reasonable that red-mediating structures would now mediate green and vice versa for green structures. Chalmers (1996) concedes that:

> To achieve such an inversion in the actual world, presumably we would need to rewire neural processes in an appropriate way, but as a logical possibility, it seems entirely coherent that experiences could be inverted while physical structure is duplicated exactly. (p. 100).

However, even in the case of this logical possibility, the existing red structures would now be indicating green without any rewiring. Now most supporters of colour inversion stress the case where someone is born with an inversion, rather than a change occurring during life. The argument is that they would learn to respond correctly with the word red to red, even though they would 'see' green, for example. Thus there would be no functional way of detecting the inversion. I would like to emphasize my case for a functional way to detect inversion.

As I said earlier (Chapter 14.0), an asymmetry can be clearly shown for the inversion of yellow and blue and also for red and green, leading to the detection of the inversion in humans. I would now present some other evidence that is difficult for the inversion hypothesis. It has been shown that there are about twice as many L cones as M cones in the human fovea (Cicerone, 1987). It has also been shown by Cicerone (1987) and Kaiser and Boynton (1996) that the position of unique yellow will change according to the relative proportions of the two types of cone. Thus it is reasonable to argue that if there is red /green inversion then the cones normally mediating red (L cones) will now be mediating green and those mediating green (M cones) will now be mediating red. It can be concluded that the number of cones mediating red will have halved compared with normals. According to Cicerone (1987) and Kaiser & Boynton (1996) this should lead to the position of unique yellow changing quite markedly to a longer wavelengths (Figure 28A). This change could be functionally detected. However, I would like to point to some recent evidence that questions this conclusion. Mollon and Jordan (1997) and Miyahara et al. (1998) have shown that heterozygous female carriers have normal unique yellows despite having low ratios of L to M cones. Otake and Cicerone (2000) in a recent paper present more evidence to support their view that the position of unique yellow depends on the L / M cone ratios. They acknowledge that the other studies cited above support the possibility that the spectral position of unique yellow may depend on factors other than the relative number of L and M cones.

It is interesting to note that if the work of Mollon and Jordan and Miyahara et al. is confirmed, it presents severe difficulties for opponent process theory. This is because unique yellow is supposed to occur where red and green inputs are balanced and equal. Thus, it is difficult to reconcile that the position of unique yellow is the same for normals and for these carriers, as each group has quite different cone ratios and thus different balance points. However, my other arguments showing that reversals of yellow and blue can be detected, still stand (chapter 14.0))

I believe that the overall evidence casts doubt on Levine's (1983) argument based on inversion. There is still a problem with colour, in that why is the qualitative effect red in the normal case? I argued that primate colour vision had evolved to detect photon energy/ wavelength aspects of the physical world. Such

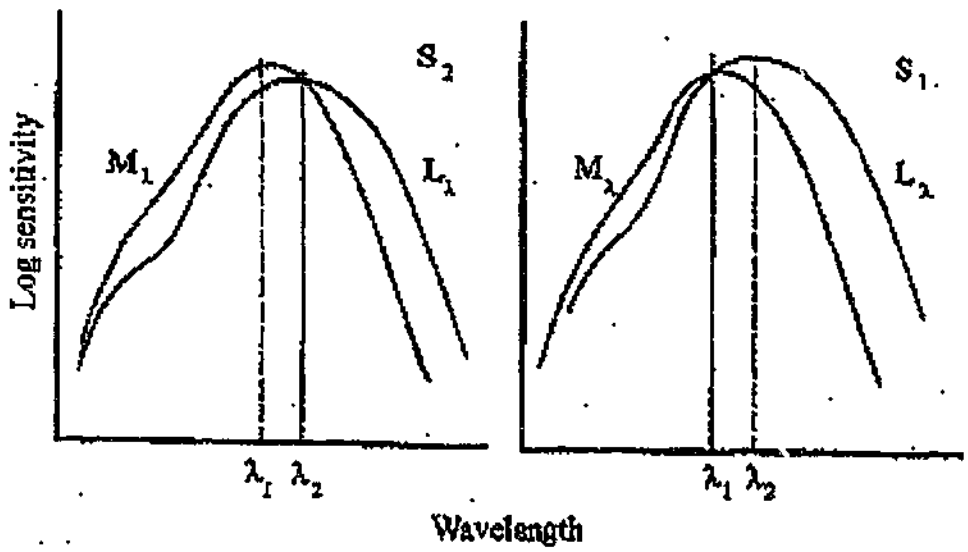


FIGURE 28 A: Subject S1, on the right, has equal populations of L - and M- cones stimulated and thus unique yellow occurs at λ_1. Subject S2, on the left, has less L-cones stimulated than M-cones and unique yellow moves up in wavelength to λ_2. Thus the position of unique yellow will change with changes in the proportions of L- and M-cones
(from Kaiser and Boynton, 1996).

an explanation would provide a possible bridge to the explanatory gap for colour, as simply being a detection of a physical variable.

In conclusion, It is argued that revelation and transparency do not apply to all aspects of colour vision. The fact that identical colours, which appear simple and monadic, can be shown to be based on different complex physical mechanisms, would appear to refute a simple revelation conception. The data presented here on the McCollough effect would also appear to bridge the explanatory gap in one small case, e.g. the qualitative phenomena can be predicted from the two-dimensional Fourier analysis and the neurophysiology of the primate brain. It is claimed that this is a local reduction to a mind/brain identity.

CHAPTER 17.0

17.1 A Possible Mind-Body Identity for Colour.

In Chapters 13.0 and 16.0, I established a possible mind-body identity for afterimages and for two-dimensional spatial frequency mechanisms. I want to apply the same line of argument in a rather speculative fashion to colour. In the last two identities, I used a set of arguments by Shaffer (1970) to establish identity. As I pointed out earlier Shaffer proposes that there are three necessary conditions for identity and the three conditions are jointly sufficient. These are that the two terms of an identity must (1) be located in the same place; (2) must occur at the same time; and (3) the presence of one must be an (empirically) necessary condition for the presence of the other.

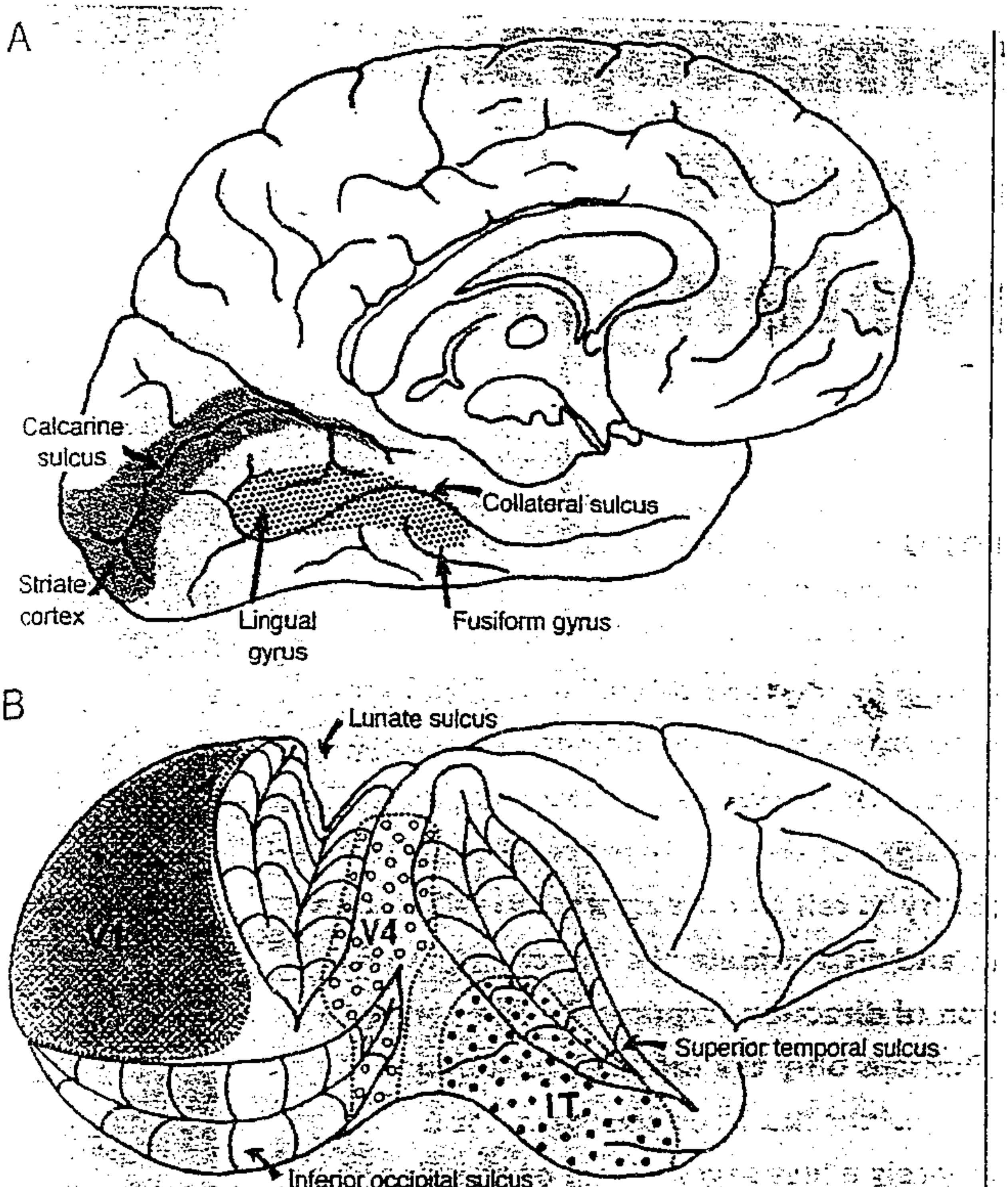
I wish to examine the concept of cerebral achromatopsia. Zeki (1990) reviews a "Century of Cerebral Achromatopsia", in which he shows clearly that there is strong evidence for the concept, I want to attempt to base on a mind / brain identity for colour on this concept. It has been shown that if people have bilateral lesions in the area of the medial occipito-cortical region, occupying the caudal fusiform and lingual gyri, then they have total bilateral achromatopsia. In this situation, these subjects report the complete loss of any colour. The whole world appears gray. However, there is virtually no loss of achromatic acuity. If the lesion is unilateral, then the subject has hemiachromatopsia. In the most clear-cut cases, there are no scotomas, thus indicating that V1 is not affected (Zeki, 1990). There has been some dispute in the literature as to the nature of the exact location of the lesion. Zeki (1990) argues that the lesion in human beings is at the site of the human version of area V4 in the macaque monkey, in which he claims to have shown to contain mainly colour sensitive cells. However, other workers (Schein et al., 1982) have disputed the high incidence of colour cells in monkey V4. In some recent work, Cowey and colleagues (Cowey and Heywood, 1997; Heywood and

Cowey, 1998; Heywood et al., 1995) have shown that lesions in monkey V4 fail to produce achromatopsia, but lesions more anteriorly in the temporal lobe do produce achromatopsia (IT in Figure 29 B). They claim that it is the equivalent area in the human brain, the removal of which is producing achromatopsia (Figure 29 A).

In an important study, Hadjikhani et al., (1998) expanded on the work of Cowey and colleagues by studying the human cortex with fMRI. Like the Heywood and Cowey (1998) suggestion, they identified an area anterior to V4, which was very sensitive to colour. They named the area V8. They also showed that the area was very responsive to coloured AI's. They presented evidence that V8 is retinotopically distinct from V4 on the basis of four different criteria; (1) V4 and V8 have separate foveal representations, approximately 3.5 cm apart along the cortical surface; (2) V4 and V8 each include separate representations of the upper visual field; (3) V8 differs from V4 in its global functional properties; (4) the nature of retinotopy in V8 is different from V4. They suggest that " V8 is involved in wavelength- dependent processing and perhaps in the conscious perception of color itself " (p. 239).

In a critical experiment, Mollon et al., (1980) tested an achromatopsia patient and showed that the retina retained normal trichromatic characteristics. In addition, they showed in the same patient that there were normal visually evoked responses recorded from the occipital lobe. These findings suggest that the visual pathways to the primary cortex were intact, but that the lesion has destroyed all extrastriate components of chromatic processing. These observations clearly suggest that colour experiences are localized in the area of the lingual and fusiform gyri or V8. I regard this evidence as support for Shaffer's first criterion.

The second criterion appears to be met as colour and the function of this area occur at the same time, as lesions elsewhere, for example in V1, produce scotomas in which all visual function disappears. The third criterion can be regarded as met, as the presence of a functioning area is necessary for the appearance of colour. I would like to conclude that experiences of having colour are identical to brain processes as proposed by Smart (1959). As Smart (1959) states that:



The putative colour area in human and macaque brain. (A) Medial view of the left hemisphere of the human brain. The dense stippling shows the striate cortex (V1), most of which is concealed in the calcarine sulcus. The lighter stippling shows the region at the junction of the li gual and fusiform gyri whose destruction leads to achromatopsia. The brain damage is usually more extensive than this in any individual patient. **(B)** Schematic lateral view of the right cerebral cortex of a macaque monkey in which the labelled sulci have been opened up. Area V4 continues on the ventral surface and V1 on the medial surface. When the inferior temporal cortex (IT) is removed, the monkeys become achromatopsic (Ref. 28), but when V4 is removed they do not.

> a sensation statement is a report of something, that something is in fact a brain process. Sensations are nothing over and above brain processes. (p. 145).

I have accepted Shaffer's three criteria as the basis for identification of sensations with brain processes in a number of cases. It is perhaps important to note that Shaffer did not believe that what he called conscious states, e. g. C-states, could be located at the same place as brain processes, e.g. B-states. It might seem odd that I am relying on arguments of a philosopher who holds quite strange views on location. For example, he says that:

> We do locate sensations in the body. But that is not to say we give location to the states of consciousness that I have when I am having a sensation. The pain is in my leg, but it is not the case that my state of being-aware-of-a-pain-in-my-leg is also in my leg. Neither is it in my head. In the case of thoughts, there is no temptation to give them location, nor to give location to the mental state of being aware of a thought. In fact, it makes no sense at all to talk about C-states as being located somewhere in the body. (Shaffer, 1970, p. 115).

I think that Lewis (1983) has given the perfect reply to this argument. He says that:

> Shaffer has argued that the identity theory is impossible because (abstract particular) experiences are, by analytic necessity, unlocated, whereas the (abstract particular) neural events that they supposedly are have a location in part of the subject's nervous system. But I see no reason to believe that the principle that experiences are unlocated enjoys any analytic, or other, necessity. Rather it is a metaphysical prejudice, which has no claim to be respected. (p. 100).

Overall, I think that the experience of having of colour can be identified with the brain processes occurring in the area in the fusiform and lingual gyri human V8.

It is interesting to look at the single unit recording evidence for these areas in the macaque to see if the cells are very sensitive to colour. This would surely be a necessary component of area mediating conscious colour. Early studies of neurons in IT did not find a high incidence of colour selective cells. Desimone et al., (1984) found only 9% of cells were selective, but Gross et al., (1972) found 48% were selective for colour. These studies reported a lot of unresponsive cells, which might be due to the recordings being carried out under anaesthetic. In a study using awake macaques, Fuster and Jervey (1982) found 37% were selective for colour. In a recent study (Komatsu et al., 1992) with awake macaques, they reported that 66% of cells were selective in a general survey, but when they concentrated on colour sensitive areas, the percentage increased to 70%.

One very interesting feature of these two studies was the very low incidence of cells responding with inhibition to colour. In the Fuster and Jervey (1982) study only 10% of the cells showed reciprocal processes i.e. excitation by one colour and inhibition by another. Komatsu et al., (1992) report only a few such cells. These data suggest that there is virtually no opponent processing going on in IT. This would support my arguments, based on the work of Piantanida and Larimer (1989) with stabilized images, that opponent processes might not be involved in the most central colour processing. That is, in the areas that I am suggesting might be mediating the conscious perception of colour. These results could also suggest that the cells are interested in colour and not colour contrast. It should be noted that in all the studies of IT, the cells had very large receptive fields with no sign of the spatially opponent receptive fields like those seen in LGN. Overall, I think that both the lesion evidence and the single unit recordings suggest that colour sensations might be generated in IT.

Although I am proposing an identity between colour experiences and neural functions in IT, I cannot conclude that this particular evidence overcomes the explanatory gap for colour. Levine (1993) still has a point when he argues why is it we see red and not blue in any situation. I would like to suggest in the case of colour that the system is detecting a physical variable, so it is just a brute fact that we see red and not blue. I agree that this is not an impressive argument. In contrast, my claims of overcoming the explanatory gap with AI's and spatial frequency filters are much stronger.

CHAPTER 18.0

18.1 Summary and Conclusions.

In this thesis, I have tried to present a physicalist account of colour and mental processes. I have addressed what Ian Gold (1998) has described as the central problem of colour, i.e. whether colour is a physical property of something in the world around us or whether it is a mental property, which is not present in the external world. In general, I have accepted a causal theory of mind as put forward by David Armstrong (Armstrong and Malcolm, 1984) who argued that

> it seems quite likely that the sole causes of this behaviour are external stimuli together with internal physiological processes, in particular physiological processes in the central nervous system, but if we accept this premiss on grounds of general scientific plausibility, and also accept the causal theory of mind, the mental must in fact be physiological. (p. 158).

One of the implications of this causal account is that if colours are also based on mental processes, then they are still part of the physical world.

. In the first few chapters, I have examined the views of Keith Campbell (1993) on colour and I have highlighted some of his criticisms of colour realism based on a number of colour phenomena. I have stressed that most subjectivists about colour have emphasized that colour phenomena such as metamers, opponent processes, simultaneous contrast, colour constancy, don't fit in with a physicalist account of colour. In chapter 3, I examined the concept of a metamer in the context of the evolution of primate colour. I put forward evidence that metamers don't occur in nature and were not present in the forest where primate vision evolved. I suggest that metamers are only able to be produced as a result of our technical inventions that produce stimuli with three or more crossings in the frequency plane. In chapter 4, I examine the evidence that colour processes are entirely neural opponent processes and subjective, because there are no counterparts in the external world. I cite evidence that suggests that the colour neural system has other properties in addition to opponent processing, which are related to the external world of colour. I am not against the concept of opponent processes. They are obviously important in colour perception. However, it does appear that colour processing is not limited to just three mechanisms, e.g. a red/green, a yellow/blue, and a black/white process. The work of Krauskopf, (1996,1997), Webster and Mollon (1991,1993,1994), and D'Zamura (1991), D'Zamura and Knoblauch (1998) all indicate that there are multiple detection mechanisms of hue within the central visual field, rather than being limited to the opponent mechanisms. I conclude that opponent processing is not as damming for physicalist explanations as has been proposed by Hardin (1988).

In chapter 5, I examined reflectance realism of Hilbert (1987) and his dependence on the retinex theory of Land (1977). I cite evidence of Young (1987) against the view that Mondrian experiments are suggesting that different colours can be perceived with light of the same wavelength coming off Mondrians. Young's measurements indicate that there are still differences in wavelength that would be perceived. I also examine colour constancy in connection with retinex theory and the evolution of primate colour vision in the forest. I conclude the colour constancy was not an important factor under these conditions. In chapter 6, I examined Campbell's (1969) arguments based on adaptation, which he argues is very difficult for a physicalist theory. I cite evidence that suggests that adaptation would not be such an important factor in the conditions of the forest and the fact that the range of colours is limited in the natural environment compared with artificially generated colours. In chapter 7, I have examined the problems for a physicalist account due to illusions of colour. Theorists such as Hardin (1993) use what are described in the literature as "subjective" colours to attack wavelength realism (Armstrong (1993), reflectance realism (Hilbert, 1987), and Smart's dispositionalism. I have suggested that these illusions can be given a topic neutral account as most of them can be used to produce colour interactions with external physical colour stimuli. That is, they are based on neural mechanisms that act as though they were responding to external stimuli. It is important to note that in stabilized image studies colours were produced that have never been seen before, i.e. red/green and yellow/blue. (Larimer and Piantanida, 1988).These authors suggest that this clearly does not support opponent processing as it indicates that the most central cortical representation of perceived colour is not an opponent process. It should also be stressed that apart from simultaneous contrast and perhaps AI's, these illusions do not occur in the natural world. Also Daw (1962) has shown that AI's are not perceived under conditions in the normal environment, due to the combination of short fixation times and normal contours inhibiting the AI.

In Chapter 8, I examine in some detail Nassau's proposal of there being 15 causes of colour, with 14 of them due to interactions of photons with electrons. I accept Nassau's claim that:

> colors come about through the interaction of light waves with electrons. Such interactions have been a central preoccupation of physics on the 20th century...indeed, color is a visible (and even conspicuous) manifestation of some subtle effects that determine the structure of matter. (Nassau, 1980, p. 106).

I accept this claim, despite the fact that Nassau (1980) goes on to say that:

> the perception of color is a subjective experience..... it seems reasonable to assume, however, that perceived color is merely the eye's measure and the brain's interpretation of the dominant wavelength or frequency or energy of a light wave. (p. 106).

Unlike Nassau, I think his evidence shows that colour is part of the executive framework of the world, because of the quantum interactions with electrons. This position is supported by Maloney's (1986) evidence that other quantum processes are involved as well as electron transitions. These all lead to broad tuning of natural coloured objects, without the complex spectra associated with metamers.

I conclude in Chapter 9 that colour can be identified with photon energy / wavelength processes (PE / W) in the world. Nassau's description of the main process is quite clear. He says that;

> An important constraint on all interactions of electromagnetic radiation with matter is the quantum-mechanical rule that says atoms can only have certain discrete states, each with a precisely defined energy; intermediate energies are forbidden. Each atom has a lowest possible energy, called the ground state, and a range of excited states of higher energy. The allowed energy states can be likened to the rungs of a ladder, although their spacing is highly irregular. Light or other radiation can be absorbed only if it carries precisely the right amount of energy to promote an atom from one rung to a higher rung. Similarly, when an atom falls from an excited state to a lower-lying one, it must emit radiation that will carry off the difference in energy between the two levels. The energy appears as a photon, or quantum of light, whose frequency and wavelength are determined by the energy difference. (p. 106).

I want to argue that it is the combination of photon energy and wavelength that is colour because these quantum interactions produce a broad spectra of wavelengths with mostly one broad peak or perhaps two (Maloney, 1986). Thus our colour system evolved without the presence of complex metamers with multiple peaks in their spectra. It should be stressed that most colour in the world in which our system evolved, is reflected colour. Apart from the sun and the odd fire, there were no emitted colours until man invented them. Lennie and D'Zmura (1988) point out that:

> An implication of these analyses is that there are no metamers in the ensemble of incandescent sources or natural daylights. (p. 346).

Thus no emitted lights during evolution would be metameric.

In Chapter 10.0, I look at the work of Akins and Hahn (2000) (A&H), who have a form of an objective theory. I examine their detailed arguments about the objective theories of colour held by Jackson (1996), Hilbert (1987) and the relational theory of Thompson (1995). I give an analysis of each of these positions in relation to A&H's comments. I then look at A&H's principle of objectivity (OP). This principle states that colour is an objective property if and only if whenever an object appears to have a certain colour, say red, there is some distal property of the object which (i) normally causes it to appear red; (ii) is tracked by the appearance of redness; and (iii) is mind independent. I give arguments in support of this principle and against A&H's conclusions.

In Chapter 11.0, I examine four other objective theories of colour. In chapter 11.2, I examine Matthen's (1999) recent theory of pluralistic realism about colour. Matthen originally espoused that colours were SSRs. Two factors caused him to change his mind. One was the arguments about opponent processes put forward by Hardin (1988). The other was the work of Thompson (1995) emphasizing ecology. Matthen (1999) claims that pigeon psychophysics proclaims the existence of hues unknown to humans. Thus he claims that not every hue is reddish or greenish or bluish or yellowish and if different organisms experience colour differently, whose experiences are we going to use to construct relations with SSRs? I suggest that the evidence for tetrachromatic vision is not clear-cut and is ambiguous. (Jacobs, 1995). While I like Matthen's concept of pluralistic realism, I think it should be based on photon energy / wavelength principles rather than different visual systems. In this chapter, I also discuss realist views put forward by J. Campbell (1993), Tye (2000) and Ross (2001). I conclude that none of them give an adequate realist theory of colour, as they base their arguments on the same colour phenomena, about which I have disputed the value of their role in colour.

In Chapter 12.0, I look at a number of objections to any primary quality account of colour. I start by examining Johnston's (1992) account of colour. Johnston combines a dispositional view of colour with a sceptical view that perception does not reveal the nature of colour. I show that some recent perceptual work of mine tells against this view. This work is presented again in more detail in Chapter 16.0 in an analysis of revelation and transparency of colour. In Chapter 12.3, I then look at the subjective approach to colour of Boghossian and Velleman (1989, 1991) (B&V). B&V argue that colour is an illusion which is projected onto objects in the world. This is an error theory of colour. They argue against a dispositional account of colour on the basis of circularity. I have examined the circularity argument in terms put forward by Watkins (1994) and Armstrong (Armstrong and Malcolm, 1984). I concede that there are difficulties in rebutting this argument, but I claim that Armstrong's topic neutral approach allows a possible solving of the issue. I then look at B&V's arguments based on after-images. I conclude that a physical basis can be given for AI's on the basis of the work of Virsu & Laurinen (1977) and Day & Webster (1989) and Anstis (1978), thus refuting that colour must be a property similar to an AI in being simply a property of the visual field and hence an illusion. I then examine B&V's (1991) arguments against a physicalist account of colour. I conclude that their arguments against physicalism fail as they depend on their epistemological intuition that we know all about colour from our visual experience, which is a revelation approach to colour.

In Chapter 12.3.4, I examine McGilvray's (1994) theory of colour and the concept of projection. McGilvray puts forward two concepts of projection. One consists of sensations being projected onto objects, thus making colours illusions. The other form consists of a belief-based projection based on positing. He says:

> They are the products of a belief-based process of construction and projection. Call it 'positing'. The concept of a posit is essentially that of a theoretical entity. A creature that has a certain kind of theory of its world posits certain kinds of entities......we obviously need colored continuants to explain perceptual beliefs of language-using humans, and so we can say that humans posit such entities. (p. 229-230).

Both forms of projection are difficult to accept being based on non-existent entities. McGilvray bases his first form on the work of Clark (1993), who argues that colour is subjective and that scaling techniques portray the relationships of colour independently of external stimuli. I argue that this work overlooks a great deal of work on CIE and OSA uniform colour scales, which are based on JND's.

In Chapter 12.3.5, I examine Westphal's (1991) views on colour. Westphal argues that physicalists about colour such as Armstrong and Smart have failed to give an adequate reductionist account. Westphal argues that psychological predicates about colour cannot be reduced to psychophysical predicates as the first stage in reducing colour to physical predicates. I examined each of Westphal's arguments and put forward some evidence against them. I conclude that Westphal's arguments against reduction are not as devastating as Hardin (1989) has claimed. However, PE / W theory still needs some further development to explain better some issues raised by Westphal (1991).

In Chapter 13.0 I look at the explanatory gap and qualia. The explanatory gap is a concept put forward by Levine (1983). Levine (1994) claims that he is a modest qualophile, who finds the nature of conscious experience to be a source of deep puzzlement, as no materialist explanation can be given for this qualitative experience. He argues that even if experiences of red were perfectly correlated with some physical state of the subject, we still would not know why it looked red and not blue, for example. Levine (1983) calls this lack of explanation the explanatory gap. In this chapter, I show that the explanatory gap can be overcome in the case of an AI. I analyse the work of Virsu and Laurinen (1977) and some unpublished work of my own. We show that a mind / identity account can be given for the illusory doubling of an AI, by the technique of pressure blinding of the eye. Thus, for the first time a complete account of a case of a mind / brain identity has been provided in that the necessary and sufficient conditions for it are shown and the effect has been clearly measured across subjects.

In Chapter 14.0 I examine the concept that consciousness and qualia are representations. Armstrong (1996) proposes that mental states are nothing but representational states. He bases his claim on the work of Tye, who argues that qualia or " phenomenology ain't in the head" (Tye, 1996a; p. 151). I examine Tye's PANIC theory about representations and conclude it does not meet either Armstrong's earlier criticisms (1968) of representative theories or his recent ones (Armstrong, 1979) about sense data and qualia.

In Chapter 15.0, I examine both Maund's (1994) and Landesman's (1989,193) theory of colour. Maund argues that as a contingent fact that nothing is actually coloured. He says that colour is a virtual property and this theory is a form of colour nihilism. Maund argues against an objective account of colour largely on the basis of opponent processes and unique hues and metamers. We have seen that these concepts do not carry the theoretical weight that they did have. Maund (1994) puts forward a rather odd pluralistic theory of colour. He says that objects with virtual colours are (1) objects with certain causal powers; (2) objects that appear a certain way; (3) objects which have a certain qualitative character, i.e. physical colour takes over the causal role, dispositional colour takes over the appearance role and phenomenal colour takes over qualitative character. This pluralistic system is hard to follow since Maund argues that virtual colours are not physical, so how can they ever have causal roles? Maund also says that three-dimensional space such as CIE space cannot be a physical space and thus must be a phenomenal space. Jackson (1995) points out that an equal JND space would overcome this problem and I cite the OSA system as an example. Overall, I claim that the PE / W theory and the JND data suggest that the virtual concept of colour is not supported. Landesman puts forward a skeptical theory of colour rather than a nihilistic one like Maund, Landesman claims that all our colour experiences are hallucinatory. However, he fails to give a detailed analysis of the current literature to support his unusual theory.

In chapter 16.0, I discuss in detail the concepts of revelation and transparency as applied to colour. I argue that the concept of revelation as applied to colour is false. I discuss the views of Johnston (1992; 1996) and McGinn (1996) on revelation and transparency. I then refer Jackson's (1996) arguments about revelation. I present evidence from some psychophysical experiments of mine (Webster et al., 1992) showing that identical colours can have different spatial frequency profiles with photons coming off at different orientations and spatial frequencies. I conclude that there is a mind/brain identity between the McCollough effect and two-dimensional spatial frequency filters in V1 and this identity overcomes the explanatory gap in this case.

In chapter 17.0, I propose a speculative case of a mind/body identity for colour. I argue on the basis of the concept of achromatopsia that colour experiences in humans are identical to neural processing in cortex IT. I indicate that both lesion evidence in the macaque and imaging evidence in humans that suggest that the critical area is not the human equivalent of monkey V4. It is important to stress that lesions in IT in humans and monkeys remove colour perception but leave visual acuity to black and white stimuli. I argue that this is another case of local reduction as proposed by Kim (1993).

My main conclusion is that there is a nondisjunctive physicalist theory of colour. I argue that colour can be reduced to broad spectra of light-waves. Thus the real colour of a surface is the light-waves emitted. I assert that colour is a physical property rather than a subjective mental property. I reject subjective theories of colour that project colour onto objects in the world. These theories are based on colour processes, which I have given alternative physicalist accounts. My physicalist wavelength theory is due to a number of quantum interactions of light with objects (Nassau, 1983; Maloney, 1986). I have called the theory photon energy/ wavelength (PE/W) as the interactions largely depend on the energy of photons striking objects. These overall quantum interactions produce broad spectra of the wavelengths emitted from both biological and non biological material. Thus colour is determined by the nature of the light waves emitted from objects.

REFERENCES

Abney, W. de W. (1910),

On changes in hue of spectrum colours by dilution with white light. *Proceedings of the Royal Society*, A21, 120-127.

Abney, W. de W. (1913),

Researches in Colour Vision and the Trichromatic Theory. London: Longmans, Green and Co.

Akins K. (1996),

Introduction. In (K. Akins,ed.) *Perception,* New York: Oxford University Press, pp. 3-17.

Akins, K. & Hahn, M. (1999),

The peculiarity of colour. in (Davis, S. ed.) *Color Perception: Philosophical, Psychological, Artistic and Computational Perspectives.* Vancouver Studies in Cognitive Science, Volume 9, New York: Oxford University Press, pp.215-247.

Akins, K. and Lamping, J. (1992),

More than mere coloring: The art of spectral vision. *Behavioral and Brain Sciences,* 15, 26-27.

Alexander, S. (1920),

Space, Time and Deity. London: Macmillan

Allman, J. M. (1999),

Evolving Brains. London: Freeman & Co

Anderson, J. (1962),

Studies in Empirical Philosophy. Sydney: Angus and Robertson.

Anstis, S., Rogers, B. and Henry, J. (1978), Interactions between simultaneous contrast and coloured afterimages. *Vision Research,* 18, 899-911.

Antony, L. M. and Levine, J. (1997),

Reduction with autonomy. in (J. E. Tomberlin, ed.) *Philosophical Perspectives, 11, Mind, Causation, and World.* Boston: Blackwell, pp. 81-105.

Arend, L. E. (1987),

How much does illuminant color affect unattributed colors, *Journal of the Optical Society of America, A*, 10, 2134-2147.

Arend, L. E. and Reeves, A.(1986),

Simultaneous color constancy. *Journal of the Optical Society of America, A,* 3, 1743-1751.

Armstrong, D. M. (1955),

Illusions of sense. *Australasian Journal of Philosophy*, 33, 88-106.

Armstrong, D. M. (1961),

Perception and the Physical World. London: Routledge and Kegan Paul.

Armstrong, D. M. (1963),

Discussion: Max Deutscher and perception. *Australasian Journal of Philosophy,* 41, 246-249.

Armstrong, D. M. (1968 a),

A Materialist Theory of Mind. London: Routledge and Kegan Paul.

Armstrong, D. M. (1968b),

The secondary qualities: an essay in the classification of theories. *Australasian Journal of Philosophy,* 46, 225-241.

Armstrong, D. M. (1973),

Epistemological foundations for a materialist theory of the mind. *Philosophy of Science,* 40, 178-193.

Armstrong, D. M. (1978),

Naturalism, materialism and first philosophy. *Philosophia, 8*, 261-276.

Armstrong, D. M. (1979),

Perception, sense data and causality. in (G. F. Macdonald ed.) *Perception and Identity.* London: The Macmillan Press. pp. 84-98.

Armstrong, D. M. (1980,

The Nature of Mind. Brisbane: University of Queensland Press.

Armstrong, D. M. (1987),

Smart and the secondary qualities. in (P. Petit, R. Sylvan and J. Norman, eds.) *Metaphysics and Morality : Essays in Honour of J. J. C. Smart,* Oxford: Blackwell, pp. 1-15.

Armstrong, D. M. (1989),

C. B. Martin, counterfactuals, causality, and conditionals. in (J. Heil, ed.) *Cause, Mind, and Reality : Essays Honoring C. B. Martin*, Dordrecht: Kluwer Academic Publishers, pp.7-16.

Armstrong, D. M. (1991),

Intentionality, perception, and causality: reflections on John Searle's Intentionality. in (E. Lepore ed.) *John Searle and his Critics*, Cambridge: Blackwell.

Armstrong, D. M. (1993),

Reply to Campbell. in (J. Bacon, K. Campbell & L. Reinhardt eds.) *Ontology, Causality and Mind.* Cambridge: Cambridge University Press, pp. 268-273.

Armstrong, D. M. (1996a),

Qualia ain't in the head. *Psyche,* 2, (31), http://psyche.cs.monash.edu.au/v2/psyche-2-31-armstrong.html.

Armstrong, D. M. (1996b),

The three waves. Unpublished Manuscript. The University of Sydney, p1-22.

Armstrong, D. M. (1996c),

Dispositions as categorical states. In (T. Crane ed.) *Dispositions , a Debate.* London: Routledge.

Armstrong, D. M. and Malcolm, N. (1984),

Consciousness & Causality. Oxford: Basil Blackwell.

Artola, A., Brocher, S. and Singer, W. (1990),

Different voltage-dependent thresholds for inducing long-term depression and long-term potentiation in slices of rat visual cortex. *Nature*, 347, 69-72.

Averill, E. W. (1992a),

The relational nature of color. *The Philosophical Review,* 101, 551-588.

Averill, E. W. (1992b),

A limited objectivism defended. *Behavioral and Brain Sciences,* 15, 27-28.

Baker, L. R. (1995),

Explaining Attitudes. Cambridge: Cambridge University Press.

Baldwin, T. (1992),

The projective theory of sensory content. in (T. Crane ed.) *The Contents of Experience,* Cambridge: Cambridge University Press.

Barlow, H. B. (1990),

A theory about the functional role and synaptic mechanism of visual after-effects. in (C. Blakemore, ed.) Vision: Coding and Efficiency, Cambridge: Cambridge University Press. pp. 363-375.

Bechtel, W. and Mundale J. (1999),

Multiple realizability revisited: Linking cognitive and neural states. *Philosophy of Science,* 66, 175-207.

Benham, E. C.(1894),

Notes. *Nature*, 51, 113-114.

Berlin, B. and Kay, P. (1969),

Basic Color Terms : Their Universality and Evolution, Berkeley: University of California Press.

Berry, R. L., Teyler, T. J. and Taizhen, H. (1989,

Induction of LTP in rat primary visual cortex: tetanus parameter. *Brain Research,* 221-227.

Bigelow, J. and Pargetter, R. (1999),

Critical Notice of Tim Crane, ed. *Dispositions A Debate*. London: Routledge.

Bigelow, J., Collins,J. and Pargetter, R. (1990),

Colouring in the world. *Mind,* 99, 279-288.

Birk,G. (1984),

Fluorescence Microscopy, Sydney: Wild Leitz.

Blauert, J. (1983),

The Psychophysics of Human Sound Localization. Cambridge, Mass.: The MIT Press.

Block, N. and Fodor, J. (1980),

What psychological states are not. in N. Block ed. *Readings in Philosophy of Psychology, Vol. 1.* Cambridge, Mass.: Harvard University Press, pp. 237-250.

Block, N. (1996),

Mental paint and mental latex. in (Villanueva, E. ed.) *Perception, Philosophical Issues,* 7, pp.19-50.

Block, N. (1997),

Anti-reductionism slaps back. in (J. Tomberlin ed.) *Philosophical Perspectives,11, Mind, Causation, and World.* Boston: Blackwell, pp. 107-132.

Block, N. (1998),

Is experiencing just representing? *Philosophy and Phenomenological Research,* LVIII, 663-670.

Block, N. (1999a),

Sexism, racism, ageism, and the nature of consciousness. *Philosophical Topics,* 26, 39-72.

Block, N. (1999b),

Jack and Jill have shifted spectra. *Behavioral and Brain Sciences.* 22, 946-947.

Bogen, J. E. (1995),

On the neurophysiology of consciousness: I. An overview. *Consciousness and Cognition,* 4, 52-62.

Bogen, J. E. (1995),

On the neurophysiology of consciousness: Part II. Containing the semantic problem. *Consciousness and Cognition,* 4, 137-158.

Boghossian, P. A. and Velleman, J. D. (1989),

Colour as secondary quality. *Mind,* 98, 81-103. reprinted in Byrne, A. and Hilbert, D. R. Volume 1. Op. Cit., pp. 81-104.

Boghossian, P. A. and Velleman, J. D. (1991),

Physicalist theories of colour. *Philosophical Review,* 100, 67-106. reprinted in Byrne, A. and Hilbert, D. R. Volume 1. Op. Cit., pp.105-136.

Borst, C. V. (1970),

The Mind / Brain Identity Theory. London: St. Martin's Press.

Bouman, M. A. (1961),

History and present status of quantum theory in vision. in (Rosenblith, W. A. (ed.) *Sensory Communication*, Cambridge, Mass., The MIT Press.

Bouman, M. A. & Walraven, P. L. (1957),

Some color naming experiments for red and green monochromatic lights. *Journal of the Optical Society of America*, 47, 834-839.

Bowmaker, J. K. (1977),

The visual pigments, oil doplets and spectral sensitivity of the pigeon. *Vision Research*, 17, 1129-1138.

Bowmaker, J. K., Astell, S., Hunt, D. M. and Mollon, J. D. (1991),

Photosensitive and photostable pigments in the retinae of old world monkeys. Journal of Experimental Biology. 156, 1-19.

Boynton, R. M. (1979),

Human Color Vision. New York: Holt, Rinehart & Winston.

Boynton, R. M. (1997),

Insights gained from naming the OSA colors. in (Hardin, C. L. & Maffi, L. (eds.)) *Color Categories in Thought and Language*. Cambridge : Cambridge University Press. pp.135-150.

Brackel, J. van and Saunders, B. A. C. (1997),

On the existence of a fixed number of unique opponent hues. in (Dickinson, C., Murray, I.& Carden, D. eds.) *John Dalton's Colour Vision Legacy*, London: Taylor Francis, pp. 393-402.

Braddon-Mitchel, D and Jackson, F. C. (1996),

The Philosophy of Mind and Cognition. Oxford: Blackwell.

Bradley, M. C. (1964),

Critical notice: philosophy and scientific realism by J. J. C. Smart. *Australasian Journal of Philosophy*, XLI, 262-283.

Brainard, D. H. and Wandell, B. A.(1986), Analysis of the retinex theory of color vision. *Journal of the Optical Society of America A.*, 3, 1651-1661.

Broackes, J. (1992),

The autonomy of colour. in (Charles, D. & Lennon, K. eds.) *Reduction, Explanation, and Realism,* Oxford: Clarendon, pp. 421-465.

Broackes, J. (1992),

Nonreductionism, content and evolutionary explanation. *Behavioral and Brain Sciences,* 15, 31-32.

Broackes, J. (1993),

Colour-a Philosophical Introduction. By Jonathan Westphal. *Philosophical Quarterly,* 43, 233-238.

Broad,C. D. (1923),

Scientific Thought. London: Routledge & Kegan Paul.

Brown, K. T. (1968

Brown, T. H., Chapman, P. F., Kairiss, E. W. and Keenan, C. L. (1988), Long-term synaptic potentiation. *Science,* 242, 724-728.

Burnham, R. W., Hanes, R. M. and Bartelson, C. J. (1963),

Color: A Guide to Basic Facts and Concepts. New York: John Wiley & Sons.

Burns, S. A., Elsner, A. E., Pokorny, J., and Smith, V. C. (1984),

The Abney effect: chromaticity coordinates of unique hues and other constant hues. *Vision Research,* 24, 479-489.

Burton, G. J. and Moorhead, I. R. (1987),

Color and spatial structure in natural scenes. *Applied Optics*, 26, 157-170.

Butterfield, J. F. (1968),

Subjective (induced) color television. *Society of Motion Picture and Television Engineers Journal,* 77, 1025-1028.

Byrne, A. (2001),

Do colours look like dispositions? Reply to Langsam and others. *Philosophical Quarterly,* 51, 238-245.

Byrne, A. and Hilbert, D, R. (1997a),

Readings on Color, Volume 1: The Philosophy of color. The MIT Press: Cambridge, Mass.

Byrne, A. and Hilbert, D. R. (1977b),

Readings on Color, Volume 2: The Science of Color. The MIT Press: Cambridge, Mass.

Byrne, A and Hilbert, D. R. (1977c),

Colors and reflectances, in (A. Byrne and D.R. Hilbert eds.) *Readings on Color, Volum 1: The Philosophy of Color.* The MIT Press: Cambridge, Mass., pp. 263-288.

Campbell, J. (1993),

A simple view of colour in (J. Haldane & C.Wright, eds.) *Reality, Representation, and Projection.* Oxford University Press, Oxford. pp. 257-268.

Campbell, K. (1969),

Colours in (R. Brown & C. D. Rollins eds.) *Contemporary Philosophy in Australia,* London: Allen & Unwin, pp 132-157.

Campbell, K. (1972),

Primary and secondary qualities. *Canadian Journal of Philosophy,* 11, 219-232.

Campbell, K. (1993),

David Armstrong and realism about colour. in (Bacon, J., Campbell, K. & Reinhardt, L. eds.) *Ontology, Causality and Mind,* Cambridge: Cambridge University Press, pp 249-268.

Campbell, K. (2001),

Review of Stroud, Barry, The quest for reality: Subjectivism and the metaphysics of colour. *Australasian Journal of Philosophy*, 79, 443-444.

Chalmers, D. (1996),

The Conscious Mind. Oxford: Oxford University Press.

Charlesworth, M. (1987),

Hacker on secondary qualities. *Mind*, 76, 386-191.

Churchland, P. M. (1985)

Reduction, qualia, and the direct introspection of brain events *The Journal of Philosophy* , LXXXII ,8-28.

Churchland, P. S. (1988),

Neurophilosophy: Toward a Unified Science of the Mind/Brain. Cambridge, Mass: The MIT Press.

Cicerone C. M. (1987),

Constraints placed on color vision models by the relative numbers of different cone classes in human fovea centralis. *Farbe*, 34, 59-66.

Clark, A. (1992),

Reductionism and subjectivism defined and defended. *Behavioral and Brain Sciences*, 15, 32-33.

Clark, A. (1996),

True theories, false colors. *Philosophy of Science*, 63, S143-S150.

Clark, A (2000),

A Theory of Sentience. Oxford: Oxford University Press.

Cohen, J. (1999),

Why asymmetries in color space cannot save functionalism. *Behavioral and Brain Sciences*, 22, 950.

Cohen, J. (2001),

Subjectivism, physicalism, or none of the above? Comments on Ross's " the location problem for color subjectivism". *Consciousness and Cognition*, 10, 94-104.

Cosmides, L. and Tooby, J. (1995),

Foreword to S. Baron-Cohen, *Mindblindness*, Cambridge, Mass.; MIT Press.

Cottrell, A. (1999),

Sniffing the camembert: on the conceivability of zombies. *Journal of Consciousness Studies*, 6, 4-12.

Cotzin, M. and Dallenbach, K. (1950,

Facial vision: The role of pitch and loudness in the perception of obstascles by the blind. *American Journal of Psychology*, 63, 485-515.

Cowey, A. and Heywood, C. Q. A. (1995),

There's more to colour than meets the eye. *Behavioural Brain Research*, 71, 89-100.

Crafts, L. W., Schneirla, T. C., Robinson, E. E. and Gilbert, R. W. (1950)

Recent Experiments in Psychology: Chapter IX, *The Perception of Obstacles by the Blind.*, New York: McGraw-Hill, pp 137-169.

Craik, K. J. W. (1940),

Origin of visual after-images. *Nature*, 145, 512.

Craik, K. J. W. and Vernon, M. D. (1941),

The nature of dark adaptation. *British Journal of Psychology*, 32, 62-81.

Crane, H. D. and Piantanida, T. P. (1983),

On seeing reddish green and yellowish blue. *Science*, 242: 1078-1080.

Crane T (editor). (1992),

The Contents of Experience, Cambridge: Cambridge University Press

Crane, T. (1996),

Dispositions A Debate. D.M.Armstrong,C. B. Martin, U. T. Place, edited by T. Crane. London: Routledge.

Creutzfeldt, O. D. and Heggelund, P. (1975),

Neural plasticity in visual cortex of adult cats after exposure to visual patterns. *Science,* 188, 1025-1027

Crooke, A. (1989),

Qualia. M.A. Thesis, Clayton, Monash University.

Davis, S. (2000),

Color Perception: Philosophical, Psychological, Artistic and Computational Perspectives. Vancouver Studies in Cognitive Science, volume 9, New York: Oxford University Press.

Day, R. H. and Webster, W. R. (1989),

Negative afterimages and the McCollough effect. *Perception and Psychophysics*, 46, 419-424.

Dedrick, D. (1995),

Objectivism and the evolutionary value of colour vision. *Dialogue,* 34, 35-44.

Dedrick, D. (1996),

Can colour be reduced to anything? *Philosophy of Science.* 63, S134-S142.

Deegan, J. F. and Jacobs, G. H. (1997),

Photopigment basis for trichromatic color vision in colobine monkeys. *American Journal of Primatology,* 44, 104.

Dennett, D. C. (1991),

Review of C. McGinn, *The Problem of Consciousness. The Times Literary Supplement*, London, May 10, p.10.

Dennett, D. C. (1992),

Hitting the nail on the head, *Behavioral and Brain Sciences*, **15**, 35.

Dennett, D. C. (1993),

Consciousness Explained. London: Penguin Books.

Derrington, A. M., Krauskopf, J. and Lennie, P. (1984),

Chromatic mechanisms in lateral geniculate nucleus of macaque. *Journal of Physiology.* **357**, 241-265.

Desimone, R., Albright, T. D., Gross, C. G., and Bruce, C. (1984),

Stimulus-selective properties of inferior temporal neurons in the macaque. *The Journal of Neuroscience,* 4, 2051-2062.

Deutscher, M. (1963),

David Armstrong and perception. *Australasian Journal of Philosophy,* **41**, 81-88.

DeValois, R. L. and DeValois, K. K. (1993),

A multi-stage color model. *Vision Research,* **33**, 1053-1065.

DeValois, R. L., Abramov, I. and Jacobs, G. H.(1966),

Analysis of response patterns of LGN cells. *Journal of the Optical Society of America,* **56**, 966-877.

De Valois, K. K., De Valois, R. L. and Yund, E. W. (1979),

Responses of striate cortical cells to gratings and checkerboard patterns. *Journal of Physiology,* **291**, 483-505.

Dominy, N. J. and Lucas, P. W. (2001),

Ecological importance of trichromatic vision in primates. *Nature*, **410**, 363-366.

Donders, F. C. (1884) ,

Farbengleichungen, *Archiv. F. Anat. U. physiol. Physiol. Abthg.*, 518-522.

Dretske, F. (1995),

Naturalizing the Mind. Cambridge, Mass.: MIT Press.

D'Zmura, M. (1991),

Color in visual search. *Vision Research*, **31**, 951-966.

D'Zmura, M.and Knoblauch, K (1998),

Spectral bandwidths for the detection of color. *Vision Research*, **38**, 3117-3128.

Endler, J. A. (1993),

The color of light in forests and its implications. *Ecological Monographs*, **63**, 1-27.

Engel, S., Zhang, X. and Wandell, B. (1997),

Colour tuning in human visual cortex measured with functional magnetic resonance imaging. *Nature*, **388**, 68-71.

Evans, R. M. (1948),

An Introduction to Color. New York: John Wiley and Sons.

Falk, D. S., Brill, D. R. and Stork, D. G. (1986),

Seeing the Light: Optics in Nature, Photography, Color, Vision and Holography. Chichester: John Wiley and Sons.

Flanagan, O. (1992),

Consciousness Reconsidered. Cambridge, Mass.: The MIT Press.

Fodor, J. (1997a),

Special sciences: still autonomous after all these years. In (J. E. Tomberlin, ed.) *Philosophical Perspectives, 11, Mind, Causation, and World.* Boston: Blackwell, pp.149-164.

Fodor, J. (1997b),

Do we have it in us? *Times Literary Supplement,* May 16, p. 3-4.

Fodor, J. (1981),

How direct is visual perception? Some reflections on Gibson's " Ecological Approach". *Cognition*, **9**, 139-196.

Foster, J. (1991),

The Immaterial Self: a Defence of the Cartesian Dualist Conception of Mind. London: Routledge.

Forsyth, D. A.(1990),

Colour constancy, in (A. Blake & T. Troscianko, eds.) *AI and the eye*, New York: John

On the logic of what it is like to be a conscious subject. *Australasian Journal of Philosophy*, **67**, 205-220.

Foss, J. E. (1995),

Materialism, reduction, replacement, and the place of consciousness in science. *The Journal of Philosophy*, **XCII**, 401-429.

Franklin, J (1986),

Are dispositions reducible to categorical properties? *The Philosophical Quarterly*, **36**. 62-64.

Fuster, J. M. and Jervey, J. P. (1982),

Neuronal firing in the inferiortemporal cortex of the monkey in a visual memory task. *The Journal of Neuroscience*. **2**, 361-375.

Garfield, S. (2000),

Mauve: How One Man Invented a Colour That Changed the World. London: Faber and Faber.

Gibson, J, J, (1966),

The senses considered as perceptual systems. Boston,Houghton Mifflin

Gibson, J. J. (1979),

The Ecological Approach to Visual Perception. Boston, Houghton Mifflin.

Goda, N. and Fujii, M. (2001),

Sensitivity to modulation of color distribution in multicolored textures. *Vision Research*, **41**, 2475-2485.

Gold, I. (1993),

Color and other illusions: A philosophical theory of vision. Ph.D, Princeton.

Gold, I. (1999), Dispositions and the central problem of color. *Philosophical Studies*, **93**, 21-44.

Gold, I. (2001),

Spatial location in color vision. *Consciousness and Cognition*, **10**, 59-62.

Goldsmith,T. H. (1990),

Optimization, constraint, and history in the evolution of eyes. *The Quarterly Review of Biology*, **65**, 281-322.

Gouras, P. (1991),

Cortical mechanisms of colour vision. in (P. Gouras ed.)*The Perception of Colour; Vision and Visual Dysfunction*, Vol 6., New York: MacMillan.

Gouras, P. and Eggers, H. (1983),

Responses or primate retinal ganglion cells to moving spectral contrast. *Vision Research*, **23**,1175-1182.

Graham, C. H. and Hsia Yun (1958),

Color defect and color theory. *Science*, **127**, 675-682.

Grandy, R. E.(1989),

A modern inquiry into the physical reality of colors. in (D. Weissbord, ed.) *Mind, Value and Culture: Essays in Honor of E. M. Adams*, Ridgeview: Atascadero pp229-245.

Griffin, D. R. (1986),

Listening in the Dark., Ithaca and London: Cornell University Press

Gross, C. G.,Rocha-Miranda, C. E. and Bender, D. B. (1972),

Visual properties of neurons in inferotemporal cortex of the macaque. *Journal of Neurophysiology*, **35**, 96-111.

Guberman, A. and Stuss, D. (1983

The syndrome of bilateral thalamic infarction. *Neurology*, **33**, 540-546.

Gustafsson, B. and Wigstrom, A. (1988),

Physiological mechanisms underlying long-term potentiation. *Trends in Neuroscience*, **11**,156-162

Guth, S. L. (1991),

Model for color vision and light adaptation. *Journal of the Optical Society of America, A*, **8**, 976.

Hacker, P. M. S. (1986),

Are secondary qualities relative? *Mind*, **95**, 180-197.

Hacking, I. (1990),

Natural kinds, in, (R. Barrett and R. Gibson, eds.) *Perspectives on Quine*. Oxford: Blackwell, pp. 129-143.

Hadjikhani, N., Liu, A. K., Dale, A. M., Cavanagh,P. and Tootell, R. B. (1998),

Retinotopy and color sensitivity in human visual cortical area V8. *Nature Neuroscience*. **1**, 235-241.

Hall, R. J. (1996),

The evolution of color vision without colors, *Philosophy of Science*, **3**, S125-S133.

Hameroff, S. R., Kaszniak, A. W. and Scott, A. C. (1996),

Towards a Science of Consciousness: The First Tucson Discussions and Debates. The MIT Press: Cambridge, Mass.

Hameroff, S. R., Kaszniak, A. W. and Scott, A. C. (1998),

Towards a Science of Consciousness II: The Second Tucson Discussions and Debates. The MIT Press: Cambridge, Mass.

Hanazawa, A.,Komatsu,H. and Murakami, I. (2000),

Neural selectivity for hue and saturation of colour in the primary visual cortex of the monkey. *European Journal of Neuroscience*, **12**,1753-1763.

Hard, A. and Sivik, L. (1986),

Distinctness of border: an alternative concept for a uniform color space. *Color Research and Application* **11**, 169-175.

Hardin, C. L. (1983),

Colors, normal observers, and standard conditions. *The Journal of Philosophy,* **80**,806-813.

Hardin, C. L. (1985

Frank talk about the colours of sense-data. *Australasian Journal of Philosophy*, **63**, 485-493.

Hardin, C. L. (1987),

Qualia and materialism: Closing the explanatory gap. *Philosophy and Phenomenological Research,* **48**, 281-298.

Hardin, C. L. (1988),

Color for Philosophers, Indianapolis: Hackett.

Hardin, C. L. (1989),

Review of David Hilbert, Color and Color Perception: A Study In Anthropocentric Realism. *Canadian Philosophical Reviews,* **9**, 47-49.

Hardin, C. L. (1989),

Review of Colour: Some Philosophical Problems from Wittgenstein By Jonathan Westphal. *Mind,* 158,146-149.

Hardin, C. L. (1989),

Reduction in visual science: a philosopher's view, *Color Research and Application,* **14**. 59-63.

Hardin, C. L. (1990a),

Why color?. *SPIE,* **1250**, 293-300.

Hardin, C. L.(1990b),

Color and illusion. In (W. G. Lycan ed.) *Mind and Cognition,* Oxford: Basil Blackwell, pp.555-564.

Hardin, C. L. (1991

Reply to Teller. *Philosophical Psychology,* **4**, 61-64.

Hardin, C. L. (1992),

The virtues of illusion. *Philosophical Studies,* **68**, 371-382.

Harman, G. (1990),

The intrinsic quality of experience in (J. E. Tomberlin ed.) *Philosophical Perspectives,4 Action Theory and Philosophy of Mind.* Atascadero: Ridgeview, pp.31-52.

Harman, ,G. (1996),

Explaining objective color in terms of subjective reactions. In (Villanueva ed.) *Philosophical Issues 7: Perception.* Atascadero: Ridgeview, pp. 1-18.

Harre, R. (1999),

Nagel's challenge and the mind-body problem. *Philosophy,* **74**, 247-270.

Harrison, B. (1967),

On describing colors. *Inquiry* **10**, 38-52.

Harrison, B. (1973),

Form and Content. Oxford, Blackwell.

Harvey, J. (2000),

Colour-dispositionalism and its recent critics, *Philosophiy and Phenomenological Research.* **LXI**, 137-155.

Hatfield, G.(1992),

Color perception and neural encoding: does metameric matching entail a loss of information? In (Hull, D., Forbes, M. and Okruhlik, K. eds.) *Proceedings of the 1992 Biennial Meeting of the Philosophy of Science Association, Vol. 1, Contributed Papers* , pp.492-504.

Heil, J. (1999),

Multiple realizability. *American Philosophical Quarterly*, **36**, 191-208.

Heil, J. (2002),

Color. Unpublished paper, pp. 1-16

Helmholtz, H. (1924),

Physiological Optics, (edited by J. P. C. Southall; 3 volumes) Rochester: Optical Society of America.

Helson, H. (1938),

Fundamental problems in color vision. I. The principle governing changes in hue , saturation, and lightness of non-selective samples in chromatic illuminatiom. *Journal of Experimental Psychology*, **23**, 439-476.

Helson, H. (1943),

Some factors and implications of color constancy. *Journal of the Optical Society of America*, **33**, 555-567.

Helson, H. and Jeffers, V. B. (1940),

Fundamental problems in color vision. II. Hue, lightness, and saturation of selective samples in chromatic illumination. *Journal of Experimental Psychology*, **26**, 1-27.

Hendley, C. D. and Hecht, S. (1949),

The colors of natural objects and terrains and their relation to visual color deficiency. *Journal of the Optical Society of America. A*, **39**, 870-873.

Hering, E. (1920/1964),

Outlines of a Theory of the Light Sense, Translated by L. M. Hurvich & D. Jameson. Cambridge, Massachusetts: Harvard University Press.

Heywood,C. and Cowey, A. (1998),

With color in mind. Nature Neuroscience, **1**, 171-173.

Hilbert, D. R. (1987),

Color and Color Perception : a Study in Anthropocentric Realism, Stanford: CSLI.

Hilbert, D. R. (1992

What is color vision? *Philosophical Studies,* **68**, 351-370.

Hilbert, D. R. and Kalderon, M. E. (2000),

The peculiarity of color in (S. Davis ed.) *Color Perception: Philosophical, Psychological, Artistic and Computational Perspectives.* Vancouver Studies in Cognitive Science, Volume 9, New York: Oxford University Press, pp.187-214.

Hill, C. S. (1997),

Imaginability, conceivability, possibility and the mind-body problem. *Philosophical Studies,* **87**, 61-85.

Hill, C. S. and Mclaughlin, B. P. (1999),

There are fewer things in reality than are dreamt in Chalmers's philosophy. *Philosophy and Phenomenological Research* , **LIX**, 445-454.

Hoffman, D. D. (2001),

The data problem for color objectivism. *Consciousness and Cognition,*_**10**, 74-77.

Holton, G. and Roller, D. H. D. (1965),

Foundations of Modern Physical Science. Reading, Mass.: Addison-Wesley.

Hooker, C. A. (1981a),

Towards a general theory of reduction. Part 1: historical and scientific setting. *Dialogue,* **20**, 38-59.

Hooker, C. A. (1981b),

Towards a general theory of reduction. Part II: Identity in reduction. Dialogue, **20**, 201-236.

Hooker, C. A. (1981c),

Towards a general theory of reduction. Part III: Cross categorical reduction. *Dialogue,* **20**, 496-529.

Horgan, T. (1984),

Jackson on physical information and qualia. *Philosophical Quarterly,* **34**, 147-152.

Horgan, T. (1997),

Kim on mental causation and causal exclusion. in (J. Tomberlin ed.) *Philosophical Perspectives, 11, Mind, Causation, and World,* Boston: Blackwell, pp. 165-184.

Hunter, R. S. and Harold, R. W. (1987),

The Measurement of Appearance. New York: John Wiley & Sons.

Hurlbert, A. (1997),

Colour vision. *Current Biology,* **7**, 400-402.

Hurvich, L. M. (1981),

Color Vision. Sunderland: Sinauer Associates.

Ingling, C. R. and Martinez-Uriegas, E. (1983),

The relationship between the spectral sensitivity and spatial sensitivity for the primate r-g X-cell channel. *Vision Research,* **12**, 1495-1500.

Jackson, F. C. (1976),

The existence of mental objects. American Philosophical Quarterly, **XII**, 33-40.

Jackson, F. C. (1977),

Perception: A representative theory. Cambridge: Cambridge Un iversity Press.

Jackson, F. C. (1982),

Epiphenomenal qualia. *Philosophical Quarterly,* **32**, 127-136.

Jackson, F. C. (1995),

Review of Barry Maund, Colours: Their Nature and Representation, Cambridge University Press, Philosophical Quarterly. **48**, 243-245.

Jackson, F. C. (1996),

The primary quality view of color. in (Tomberlin, J. E. ed.) *Philosophical Perspectives, 10, Metaphysics, Cambridge MA.:* Blackwell., pp199-220.

Jackson, F. C. (1997),

Three questions about consciousness. *Psyche,* **3**, http://psyche.cs.monash.edu.au/v3/psyche-3-05-jackson.html, 1-4.

Jackson, F. C. (1998),

Causal roles and higher-order properties. *Philosophy and Phenomenological Research,* **LVIII**, 657-661.

Jackson, F. C. (2000),

Philosophizing about color. In (S. Davis ed.) *Color Perception: Philosophical, Psychological, Artistic and Computational Perspectives.* Vancouver Studies in Cognitive Science, Volume 9, New York: Oxford University Press, pp.152-162.

Jackson, F. C. (2002),

Representation and experience in (Clapin, H., Slezk, P., and Staines, P. eds.) *Representation in Mind: New Approaches to Mental Representation* Wesport: Praeger (in press)

Jackson, F. C. and Pargetter, R. (1987),

An objectivists guide to subjectivism about color. *Revue International de Philosophie,* **68**, 221-263.

Jackson, F. C. and Pettit, P.(1990),

Causation in the philosophy of mind. *Philosophy and Phenomonological Research,* L, 195-214.

Jacquette, D. (1995),

Color and Armstrong's color realism under the microscope. *Stud. Hist. Phil. Sci.*. **26**, 389-406.

Jacobs, G. H. (1981

Comparative Color Vision, New York: Academic Press.

Jacobs, G. H. (1992),

Data and interpretation in comparative color vision. Behavioral and Brain *Sciences*, **15**, 40-41.

Jacobs, G. H., Neitz, M., Deegan, J. F. and Neitz, J. (1996),

Trichromatic colour vision in New World Monkeys. *Nature*, **382**, 156-1.

Jacab, Z. (2001),

Commentary on P. W. Ross: the location problem for color subjectivism. *Consciousness and Cognition*, **10**, 133-139.

Jameson, K. and D'Andrade, R. G. (1997),

It's not really red, green, yellow, blue: an inquiry into perceptual color space. in (C. L. Hardin and L. Maffi eds) *Color Categories in Thought and Language*. Cambridge, Cambridge University Press. pp. 295-319.

Johnston, M. (1992),

How to speak of the colors. *Philosophical Studies*, **68**, 221-263.

Johnston, M. (1996),

Is the external world invisible? *Philosophical Issues*, **7**, 187-198.

Joske, W. (1992),

The Mind-body problem. in (J. T. J. Srzednicki and D. Wood, eds.) *Essays on Philosophy in Australia*, Dordrecht: Kluwer Academic Publishers.

Judd, B. D. and Wyszecki, G. (1963),

Color in Business, Science, and Industry, New York: Wiley

Kaiser, P. K. and Boynton, R. M. (1996),

Human Color Vision, Washington: Optical Society of America

Katz, J. J, (1998),

The problem in twentieth-century philosophy. *The Journal of Philosophy,* **XCV**, 547-575.

Kauzmann,W. (1957),

Quantum Chemistry. New York: Academic Press.

Kay, P., Berlin, B. and Merrifield, W. R. (1991),

Biocultural implications of systems of color naming. *Journal of Linguistic Anthropology,* **1**, 12-25.

Kelly. D. H. (1976),

Pattern detection and the two-dimensional Fourier transform: Flickering checkerboards and chromatic mechanisms. *Vision Research,* **16**, 277-287.

Kim, J. (1993),

Supervenience and Mind. Cambridge University Press, Cambridge.

Kim, J. (1997),

The mind-body problem: Taking stock after forty years. in (J. E. Tomberlin ed.) *Philosophical Perspectives, 11, Mind, Causation, and World.* Boston: Blackwell, pp. 185-208.

Kingdom, F. A. A. and Mullen, K.T. (1995),

Separating colour and luminance information in the visual system. *Spatial Research,* **9**, 191-209.

Kauzmann, W. (1967),

Quantum Chemistry. Academic Press: New York.

Komatsu, H. (1993),

Neural coding of color and form in the inferior temporal cortex of the monkey.*Biomedical Research,* **14**, Supplement 4, 7-13.

Komatsu, H (1997),

Neural representation of color in the inferior temporal cortex of the macaque monkey. In (Sakata, H, Mikami, a. and Fuster, J. M. eds.) *The Association Cortex--Structure and Functions.* Amsterdam: Harwood Academic Publishers.

Komatsu, H. and Ideura, Y. (1993),

Relationships between color, shape, and pattern selectivities of neurons in the temporal cortex of the monkey. *Journal of Neurophysiology.* **70**, 677-694.

Komatsu, H., Ideura, Y., Kaji, S. and Yamane, S. (1992),

Color selectivity of neurons in the inferior temporal cortex of the awake macaque monkey. *The Journal of Neuroscience,* **12**, 408-424.

Komatsu, Y., Fujii, K., Sakaguchi, H. and Toyama, K. (1988),

Long-term potentiation of synaptic transmission in kitten visual cortex. *Journal of Neurophysiology,* **59** 124-141

Krauskopf, J. (1963),

Effect or retinal stabilization on the appearance of heterochromatic targets. *Journal of the Optical Society of America,* **53** 741-744.

Krauskopf, J. (1997),

The paucity of evidencs for cardinal mechanisms. In (C. Dickinson, I. Murray, and D, Carden eds.) *John Dalton's Colour Vision Legacy* . London: Taylor Francis, pp. 431-440.

Krauskopf, J.,Williams, D. R., and Heeley D. R. (1982),

Cardinal directions in color space. *Vision Research,* **22**, 1123-1131.

Krauskopf, J.,Wu, Hai-Jung, and Farell, B. (1996),

Coherence, cardinal directions and higher-order mechanisms. *Vision Research,* **36**,1235-1245.

Krauskopf, J.,Williams, D. R., Mandler, M. B.and Brown, A. M. (1986),

Higher order color mechanisms. *Vision Research* , **26** 23-32.

Kraut, R. (1992),

Objectivity of color and the color of objectivity. *Philosophical Studies*, **8**, 265-287.

Kuehni, R. G. (1997),

Color: An Introduction to Practice and Principles. New York: John Wiley & Sons.

Land, E. H. (1977),

The retinex theory of color vision. *Scientific American*, **237**, no. 6, 108-128.

Land, E. H. (1983),

Recent advances in retinex theory and some implications for cortical computations: color vision and the natural image. *Proceedings of the National Academy of Sciences USA*, 80, 5163-5169.

Land, E. H. and McCann, J. J. (1971),

Lightness and retinex theory. *Journal of the Optical Society of America*, **61**, 1-11.

Landesman,C. (1989),

Color and Consciousness. Philadelphia: Temple University Press.

Landesman, C. (1993),

The Eye and the Mind. Dordrecht: Kluwer Academic Publishers.

Langsam, H. (2000),

Why colours do look like dispositions. *The Philosophical Quarterly*, **50**, 68-75.

Larimer, J. and Piantanida, T.(1988),

The impact of boundaries on color: stabilized image studies. *SPIE*, **901**, 241

Le Grand, Y. (1968),

Light, Colour and Vision, London: Chapman and Hall.

Leibman, P. A.(1977),

Microspectrophotometry of photoreceptors in (H. J. A. Dartnall ed.) *Hand book of Sensory Physiology, vol. VII/1:The Photochemistry of Vision.* Berlin , Springer-Verlag.

Lennie, P. and D'Zmura, M. (1988),

Mechanisms of color vision. *CRC Critical Reviews in Neurobiology,* **3**, 333-400.

Lennie, P., Krauskopf, J. and Sclar, G. (1990),

Chromatic mechanisms in striate cortex of macaque. *Journal of Neuroscience.* **10**, 649-669.

Levine, J. (1987),

Materialism and qualia: The explanatory gap. *Pacific Philosophical Quarterly,* **64**, 354-361.

Levine J. (1991),

Cool red [1]. *Philosophical Psychology,* **4**,27-40.

Levine, J. (1992),

Objectivism- subjectivism: A false dilemma? *Behavioral and Brain Sciences.* **15**, 42-43.

Levine, J. (1993),

On leaving out what it's like. in (M. Davies and G. W. Humphreys, eds.) *Consciousness: Psychological and Philosophical Essays.* Oxford: Blackwell, pp119-136.

Levine, J. (1994),

Out of the closet: A qualophile confronts qualophobia. *Philosophical Topics,* **22**, 107-126.

Levine, J. (1995),

Qualia: intrinsic, relational or what? in (T. Metzinger, ed.) *Conscious Experience.* Schöningh, Imprint Academic, pp 277-292.

Levine, J. (1997a),

Recent work on consciousness. *American Philosophical Quarterly,* **34**, 381-406.

Levine, J. (1997b),

Are qualia representational? A critical notice of Michael Tye's Ten Problems of Consciousness. *Mind and Language*. **12**, 101-113.

Levine, J. (1998),

Conceivability and the metaphysics of mind. *Nous,* **32**, 449-480.

Lewis, D. (1983a),

Individuation by acquaintance and by stipulation. *Philosophical Review,* **92**, 3-32.

Lewis D, (1983b),

Philosophical Papers, Volume 1. . Oxford University Press : Oxford.

Lewis, D. (1_990),

What experience teaches. in (Lycan W., ed.) *Mind and Cognition,* Oxford: Blackwell.

Lewis D. (1997a),

Naming the Colours. *Australasian Journal of Philosophy,* **75**, 325-342.

Lewis, D. (1997b),

Finkish dispositions, *The Philosophical Quarterly. 47,* **143**-158.

Lindburg, D. G. (1977),

Feeding behavior and diet of rhesus monkeys (Macaca mulatta) in Siwalik forest in north India. in (Clutton-Brock, T. H., ed.) *Primate Ecology,* London: Academic Press, pp. 223-250.

Liss, A. M. and Tipton P. L. (1997),

The discovery of the top quark. *Scientific American,* 277, (September), 36-41.

Livingstone M. S. and Hubel, D. H. (1984),

Anatomy and physiology of a color system in the primate visual cortex. *The Journal of Neuroscience*, 4, 309-356.

Loar, B. (1999),

David Chalmers's The Conscious Mind. *Philosophy and Phenomenological Research*, LIX, 465-472.

Locke, J (1690/1975)

An Essay Concerning Human Understanding. Ed. P. H. Nidditch, Oxford: Oxford University Press.

Lopes, D. M. M. (2000)

What is it like to see with your ears? The representational theory of mind. *Philosophy and Phenomenological Research*, LX, 439-455.

Lucas, P. W., Darvell B. W., Lee, P. K. D., Yuen, T. B. D. and Choong, M. F. (1998),

Colour cues for leaf food selection by long-tailed macaques (Macaca fascicularis) with a new suggestion for the evolution of trichromatic colour vision. *Folia Primatol*, 69, 139-152.

Lund, D. H.(1994),

Perception, Mind and Personal Identity : a Critique of Materialism . Lanham: University Press of America.

Lycan, W. G. (1996a)

Layered perceptual representation. *Philosophical Issues*, 7, 81-100.

Lycan, W. G. (1996b),

Consciousness and Experience. Cambridge, Mass.: MIT Press.

Lythgoe, J. N. (1979),

The Ecology of Vision, Oxford: Oxford University Press.

MacAdam, D. L.(1985)

Color measurement: Theme and Variation. New York: Springer Verlag.

MacDonald, C. (1990),

Weak externalism and mind-body identity. *Mind,* **99**, 387-404.

Macdonald, C. (1992),

Mind-Body Identity Theories. Routledge, New York

MacDonald, C. (1992),

Weak externalism and psychological reduction. in (D. Charles, and K. Lennon, eds.) *Reduction, Explanation, and Realism.* Oxford: Clarendon Press, pp133-154.

MacDonald, C. (1995),

Psychophysical supervenience, dependency, and reduction. in (E. E. Savellos, and U. D. Yalcin, eds.) *Supervenience.* Cambridge: Cambridge University Press. pp.140-157.

Maloney, L. T. (1986),

Evaluation of Linear Models of Surface Reflectance with Small Numbers of Parameters. *Journal of the Optical Society of America A,* **3**, 1673-1683.

Maloney, L. T. and Wandell, B. A. (1986),

Color constancy: a method of recovering surface spectral reflectance. *Journal of the Optical Society of America, A,* **3**, 29-33.

Malsburg, Von der C. (1995

Binding in models of perception and brain function. *Current Opinion in Neurobiology,* **5**, 520-526.

Martin, C. B. (1994),

Dispositions and conditionals. The Philosophical Quarterly, **44**, 1-8.

Martin, C. B. (1996a),

How it is: Entities, absences and voids, *Australasian Journal of Philosophy*. **74**, 57-65.

Martin, C. B. (1996b),

Properties and dispositions, in (T. Crane, ed.) *Dispositions*, London, Routledge, pp.71-87.

Martin, C. B. and Heil, J. (1998),

Rules and powers. *Philosohical Perspectives, 12, Language, Mind, and Ontology*, 283-312.

Martinez-Uriegas, E. (1994),

Chromatic-achromatic multiplexing in human color vision. in (D. H. Kelly ed.) *Visual Science and Engineering*, New York: Dekker, pp. 117-187.

Matthen, M. (1988),

Biological functions and perceptual content. *The Journal of Philosophy*, **LXXXV**, 5-28.

Matthen M. (1992),

Color vision: Content versus experience. *Behavioral and Brain Sciences*, **15**, 46-47.

Matthen, M. (1999),

The disunity of color. *The Philosophical Review*, **108**, 47-84

Matthen, M. (2001),

What colors? Whose colors? *Consciousness and Cognition*, **10**, 117-124.

Maund, J.B. (1981),

Colour—a case for conceptual fission. Australasian Journal of Philosophy, **59**, 308-322.

Maund, B. (1994),

Colours: Their Nature and Representation, Cambridge: Cambridge University Press.

Maund, B. (2000),

Color. in *Stanford Encyclopedia of Philosophy.* http://setis.library.usyd.edu.au/stanford/entries/color/, pp. 1-26.

McCann, J. J., McKee, S. P. and Taylor, T. H.(1976),

Quantitative studies in retinex theory. *Vision Research,* **16**, 445-458.

McCollough. C. (1965),

Color adatation of edge detectors in the human visual system. *Science,* **149**, 1115-1116.

McGilvray, J. A. (1983),

To color. *Synthese,* **54**, 37-70.

McGilvray, J. A.(1994),

Constant colors in the head. *Synthese,* **100**, 197-239.

McGilvray, J. A. (2001),

The location problem reconsidered: a reply to Ross. *Consciousness and Cognition,* **10**, 63-73.

McGinn, C. (1989),

Can we solve the mind-body problem? *Mind,* **98**, 349-366.

McGinn, C. (1991a),

The Problem of Consciousness. Oxford: Blackwell.

McGinn, C. (1996),

Another Look at Color. *The Journal of Philosophy,* **XCIII**, 537-553.

McGinn, M. (1991b

On two recent accounts of colour. *The Philosophical Quarterly,* **41**, 316-324

Michael, C. R. (1978),

Color vision mechanisms in monkey striate cortex: Simple cells with dual opponent-color receptive fields. *Journal of Neurophysiology*, **41**, 1233-1249.

Miller, A. (1997),

Boghossian on reductive dispositionalism about content: The case strengthened. *Mind and Language*, **12**, 1-10.

Milton, K. (1980),

The Foraging Strategy of Howler Monkeys. New York: Columbia University Press.

Mollon, J. D. (1989),

"Tho'she kneel'd in that place where they grew...". *Journal of Experimental Biology*, **146**, 21-38.

Mollon, J. D. (1987),

On the nature of models

Uses and evolutionary origins of primate colour vision. In (Cronly-Dillon, J. R. & Gregory, R. L. eds.) *Evolution of the Eye and Visual System, Vision and Visual Dysfunction*, Vol. 2, London: MacMIllan, pp. 306-319

Mollon, J. D. (1995),

Seeing colour. In (Lamb, T. & Bourriau, J. eds.) *Colour: Art and Science*. Cambridge: Cambridge University Press, pp. 127-150..

Mollon, J. D. (1997

On the basis of velocity cues alone ": some perceptual themes 1946-1996. *The Quarterly Journal of Experimental Psychology*, **50A**, 859-878.

Mollon, J. D. (2000),

" Cherries among the leaves": the evolutionary origins of color vision. In (S. Davis ed.) *Color Perception: Philosophical, Psychological, Artistic and Computational Perspectives.* Vancouver Studies in Cognitive Science, Volume 9, New York: Oxford University Press, pp.10-30.

Mollon, J. D. and Cavonius, C. R. (1987),

The chromatic antagonisms of opponent process theory are not the same as those revealed in studies of detection and discrimination. in (Verriest, G. ed.) *Colour Vision Deficiencies*. Dordrecht: Martinus Nijhoff / Dr. W. Junk Publishers, pp. 473-483.

Mollon, J. D. and Jordan, G. (1997),

On the nature of unique hues. in (Dickinson, C., Murray, I.& Carden, D eds.) *John Dalton's Colour Vision Legacy*. London : Taylor Francis, pp. 381-392.

Molnar, G. (1999)

Are dispositions reducible? *The Philosophical Quarterly*, **49**, 1-17.

Nagel, T. (1974),

What its like to be a bat. *Philosophical Review*, **83**, 435-440.

Nagel, T. (1986),

The View from Nowhere. Oxford: Oxford University Press.

Nagel, T. (1998),

Conceiving the impossible and the mind-body problem. *Philosophy*, **73**, 337-352.

Nagle, M. G. and Osorio, D. (1993),

The tuning of human photopigments may minimize red-green chromatic signals in natural conditions. *Proc. R. Soc. Lond.* B, **232**, 209-213.

Nassau, K. (1980),

The causes of color. *Scientific American*, **243(4)**, 106-203.

Nassau, K. (1983),

The Physics and Chemistry of Color. New York: John Wiley & Sons

Nassau, K, (1998),

The fifteen causes of color. in (K. Nassau Ed.) *Color for*

Science, Art and Technology. Amsterdam: Elsevier, pp.123-168.

Nathans, J., Piantanida, T. P., Eddy, R. L., Shows, T. B. and Hogness, D. S. (1986),

Molecular genetics of inherited variation in human color vision. *Science*, 232, 203-210.

Newsome, W. T., Salzman, C. D., Murasugi, C. M. and Britten, K. H. (1991),

Manipulating perceptual decisions by microstimulation of extrastriate visual cortex. in (A. Gorea, ed.) *Representations of Vision*, Cambridge: Cambridge University Press, pp.125-1

O'Neil, W. M. (1958),

Basic issues in perceptual theory. *Psychological Review*, **65**, 348-361.

O'Neil, W. M. (1968),

Realism and behaviorism. *Journal of the History of the Behavioral Sciences*, **IV**, 152-160

O'Shaughnessy, B. (1986),

Secondary qualities. Pacific Philosophical Quarterly, **67**, 153-171.

Osorio, D. (1997),

A functional view of cone pigments and colour vision. in (C. Dickinson, I. Murray & D. Carden , eds.) *John Dalton's Colour Vision Legacy*, London: Taylor & Francis, pp. 483-490.

Osorio, D. and Vorobyev, M. (1996),

Colour vision as an adaptation to frugivory in primates. *Proc. R. Soc.* B, **263**, 593-599.

Otake, S. and Cicerone C. M. (2000),

L and M cone relative numerosity and red-green opponency from fovea to midperiphery in the human retina. Journal of the Optical Society of America, A. **17**, 615-627.

Palmer, S. E. (1999),

Color, consciousness, and the isomorphism constraint. *Behavioral and Brain Sciences,* **22**, 923-989.

Peacocke, C. (1983),

Sense and Content. Oxford, Clarendon Press.

Peacocke, C. (1984),

Colour concepts and colour experience, *Synthese,* **58**, 365-381.

Piantanida, T. and Larimer, J. (1989),

The impact of boundaries on color: stabilized image studies. *Journal of Imaging Technology,* **15**, 58-63.

Place, U. T. (1956),

Is consciousness a brain process? *British Journal of Psychology.* **47**, 208-219.

Place, U. T. (1970),

Is consciousness a brain process? In (C. V. Borst ed.) *The Mind/Brain Identity Theory,* London: St. Martin's Press, pp. 42-5

Place, U. T. (1988),

Thirty years on... is consciousness still a brain process? *Australasian Journal of Philosophy.* 66, 208-219.

Pridmore, R. W. (1999),

Unique and binary hues as functions of luminance and illuminant color temperature, and relations with invariant hues. *Vision Research,* **39**, 3892-30908.

Priest, G. (1989),

Primary qualities are secondary qualities too. *British Journal of Philosophy of Science*, **40**, 9-37.

Pringsheim, P.(1949

Fluorescence and Phosphorescence. New York: Interscience Publishers.

Prior, E. W., Pargetter, R. and Jackson, F. (1982),

Three Theses about dispositions. *American Philosophical Quarterly*, **19**, 251-257.

Purdy, D. (1931),

On the saturations and chromatic thresholds of the spectral colors. *British Journal of Psychology (General Section)*, **21**, 283-313.

Purdy, D. McL.(1931),

Spectral hue as a function of intensity. *The American Journal of Psychology*, 33,541-559.

Purdy, D. (1937),

The Bezold- Brücke phenomenon and contours for constant hue. *American Journal of Psychology*, **39**, 313-315.

Regan, B. C., Julliot, C., Simmen, B., Vienot, F., Charles-Dominique, P. and Mollon, J. D. (2001),

Fruits, foliage and the evolution of primate colour vision. *Phil. Trans. R. Soc. Lond. B*, **356**, 229-283.

Raffman, D. (1995),

On the persistence of phenomenology. In (Metzinger, T. ed.) *Conscious Experience*, Schöningh: Imprint Academic, pp. 293-

Rorty, R. (1970),

Mind-body identity, privacy and categories. in (C. V. Borst ed.) *The Mind / Brain Identity Theory*, London, St. Martin's Press, pp. 187-213.

Rosenthal D. M. (1976),

Mentality and neutrality. *The Journal of Philosophy*, **LXXIII**, 386-415.

Rosenthal, D. M. (2001),

Color, mental location, and the visual field. *Consciousness and Cognition*, **10**, 85-93.

Ross, P. W. (1999),

The appearance and nature of color. *The Southern Journal of Philosophy*, **37**, 227-252.

Ross, P. W. (2000),

The relativity of color. *Synthese*, **123**, 105-129.

Ross, P. W. (2001a),

The location problem for color vision. *Consciousness and Cognition*, **10**, 42-58.

Ross, P. W. (2001b),

Locating color: further thoughts. Consciousness and Cognition. **10**, 146-156.

Schein, S. J. and Desimone, R. (1990),

Spectral properties of V4 neurons in macaque *The Journal of Neuroscience*. **10**, 3369-3389.

Schiffer, S. (1990),

Physicalism. in (J. E. Tomberlin ed.) *Philosophical Perspectives 4 Action Theory and Philosophy of Mind*. Atascadero. Ridgeview, pp.153-186.

Sellars, W.(1963),

Science, Perception and Reality. London: Routledge & Kegan Paul.

Shaffer, J. (1970),

Could mental states be brain processes? in (C. V. Borst ed.), *The Mind / Brain Identity Theory*, , London, St. Martin's Press p. 113-122.

Sherrington, C. (1947),

The Integrative Action of the Nervous System , Cambridge: Cambridge University Press.

Shoemaker, S, (1990),

Qualities and qualia: what's in the mind? *Philosophy and Phenomenological Research,* **50**, 109-131.

Shoemaker, S. (1998),

Two cheers for representationalism, *Philosophy and Phenomenological Research*, **LVIII**, 671-678.

Shoemaker, S. (1999),

On David Chalmers's The Conscious Mind. *Philosophy and Phenomenological Research,* **LIX**, 439-444.

Singer,W. and Gray, C. M. (1995),

Visual Feature Integration and the Temporal Correlation Hypothesis. *Annual Review of Neuroscience* **18**, 555-586.

Sivik, L. (1997),

Color systems for cognitive research. In (Hardin, C. L. & Maffi, L. eds) *Color Categories in Thought and Language,* Cambridge: Cambridge University Press, pp.163-193.

Smart J. J. C. (1959),

Sensations and brain processes. *Philosophical Review,* **68**, 141-156.

Smart, J. J. C. (1961),

Colours. *Philosophy*, **36**, 128-142.

Smart, J. J. C. (1975),

On some criticisms of a physicalist theory of colors. in (Chung-Ying Cheng ed.) *Philosophical Aspects of the Mind-Body Problem,* Honolulu: University Press of Hawaii. pp. 54-63.

Smart, J. J. C. (1995),

'Looks red' and dangerous talk. *Philosophy,* **70**, 545-554.

Smith, A. D. (1977),

Dispositional properties. Mind, **86**, 439-445.

Smith, C. C. (1977),

Feeding behaviour and social organization in howling monkeys. in (Clutton-Brock, T. H. ed.) *Primate Ecology,* London: Academic Press, pp 97-126.

Smith, M. A. (1986),

Peacocke on red and red'. *Synthese,* **68**, 559-576.

Smith, M. A. (1993),

Colour, transparency, mind-independence in (J. Haldane . & C.Wright, . eds.) *Reality, Representation, and Projection.* Oxford University Press, Oxford. pp. 269-277.

Smith, M. A. (1994),

The Moral Problem. Oxford: Basil Blackwell.

Snodderly, D. M. (1979),

Visual discrimination encountered in food foraging by a neotropical primate: Implications for the evolution of color vision. in (Burtt Jr., E. H., ed.) *The Behavioral Significance of Color.* Garland: STPM Press.

Stalnaker, R. (1989),

On what's in the head. in (Tomberlin., J. E., ed.) *Philosophical Perspectives, 3: Philosophy of Mind and Action Theory,* Atascadero: Ridgeview Publishing Co., pp 287-316.

Strawson, G. (1989),

Red' and Red. *Synthese,* **78**. 193-232.

Stroud, B. (2000),

The Quest for Reality: Subjectivism and the Metaphysics of Colour. Oxford: Oxford University Press

Stufflebeam, R. S. and Bechtel, W. (1997),

PET: exploring the myth and the method. *Philosophy of Science,* **64**, S95-S106.

Sumner, P. and Mollon, J. D. (2000),

Catarrhine photopigments are optimized for detecting targets against a foliage background. *The Journal of Experimental Biology,* **203**, 1963-1986.

Sumner, P. and Mollon, J. D. (2000),

Chromaticity as a signal of ripeness in fruits taken by primates. *The Journal of Experimental Biology,* **203**, 1987-20

Taylor, C.(1970),

Mind-body identity, a side issue? in (C. V. Borst ed.) *The Mind / Brain Identity Theory,* London, St. Martin's Press, pp. 231-241.

Thomas, N. J. T. (2001),

Color realism; toward a solution to the " hard problem". Consciousness and Cognition, **10**, 140-145.

Thompson, E. (1995),

Colour Vision, London: Routledge.

Thompson, E. (2000),

Comparative color vision: qualityspace and visual ecology. In (S. Davis ed.) *Color Perception: Philosophical, Psychological, Artistic and Computational Perspectives.* Vancouver Studies in Cognitive Science, Volume 9, New York: Oxford University Press, pp.163-186.

Thompson, E., Palacios, A. and Varela, F. J. (1992),

Ways of coloring: comparative color vision as a case study for cognitive science. *Behavioral and Brain Sciences,* **15**, 1-74.

Tolliver, J. T. (1994),

Interior colors. *Philosophical Topics,* **22**, 411-441.

Treisman, A. (1996),

The binding binding problem. *Current Opinion in Neurobiology,* **6**, 171-178.

Turner, R. Steven, (1994),

In the Eye's Mind: Vision and the Helmholtz-Hering Controversy. Princeton: Princeton University Press.

Tye, M. (1996a),

Ten Problems of Consciousness. Cambridge, Mas.: The MIT Press.

Tye, M. (1996b),

Perceptual experience is a many-layered thing. in (E. Villanueva, ed.) , *Perception, Philosophical Issues,* **7**, 117-126.

Tye, M. (1998),

Précis of Ten Problems of Consciousness. *Philosophy and Phenomenological Research,* **LVIII**, 649-656.

Tye, M. (1998),

Response to discussants. Philosophy and Phenomenological Research, **LVIII**, 679-687

Tye, M. (2000),

Consciousness, Color, and Content. Cambridge, Mass.: A Bradford Book.

Valberg, A. (1971),

A method for the precise determination of achromatic colours including white. Vision Research, **11**, 157-160.

Valberg, A. (2001),

Unique hues: an old problem for a new generation. *Vision Research,* **41**, 1645-1657.

Valberg, A. and Lange-Malecki, B. (1990), Colour constancy" in Mondrian patterns: a partial cancellation of physical chromacity shifts by simultaneous contrast. *Vision Research*, **30**, 371-380.

Van Orden, G. C. and Paap, K. R. (1997),

Functional neuroimages fail to discover pieces of mind in the parts of the brain. *Philosophy of Science*, **64**, S85-S94.

Velmans, M. (1990),

Consciousness, brain and the physical world. *Philosophical Psychology*, **3**, 77-99.

Velmans, M. (1993),

A reflexive science of consciousness. in (Bock, G. R. and Marsh, J., eds.) *Experimental and Theoretical Studies of Consciousness.* CIBA Foundation Symposium 174, Chichester: John Wiley & Sons, pp 81-99.

Virsu,V. and Laurinen, P. (1977),

Long-lasting afterimages caused by neural adaptation. *Vision Research*, **17**. 853-860.

Vos, J. J. (1986),

Are unique and invariant hues coupled? *Vision Research*, **26**, 337-

Walraven, P. L.(1962),

On the Mechanisms of Colour Vision. The Netherlands: Institute for Perception RVO- TNO.

Watkins, M. (1994),

Dispositionalism, ostension and austerity. Philosophical Studies, 73, 55-86.

Watkins, M. (1997),

What our colour experiences don't teach us: a reply to Boghossian and Velleman. *Dialogue* **36**, 783-786.

Webster, M. A. (1996),

Human colour perception and its adaptation. *Network: Computation in neural systems,* **7**, 587-634.

Webster, M. A. and Mollon, J. D. (1991),

Changes in colour appearance following post-receptoral adaptation. *Nature.* **349**, 235-238.

Webster, M. A. and Mollon, J. D. (1993),

Contrast adaptation dissociates different measures of luminous efficiency. *Journal of the Optical Society of America A.* **10**,1332-1340.

Webster, M. A. and Mollon, J. D. (1994),

The influence of contrast adaptation on color appearance. *Vision Research,* **34**,1993-2020.

Webster, M. A. and Mollon, J. D. (1997),

Adaptation and the color statistics of natural images. *Vision Research,* **37**, 3283-3298.

Webster, M. A., Wade, A. and Mollon, J. D. (1996),

Color in natural images and its implications for visual adaptation. *SPIE Proceedings,* **2657**, 144-152.

Webster, M. A., Miyahara, E., Malkoc, G., and Raker, V. E. (2000a),

Variations in normal color vision. I. Cone-opponent axes. *Journal of the Optical Society of America. A* . **17**, 1535-1544.

Webster, M. A., Miyahara, E., Malkoc, G., and Raker, V. E. (2000b),

Variations in normal color vision. II. Unique hues. *Journal of the Optical Society of America, A* **17**, 1545-1555.

Webster, W. R. (2002a),

A case of mind/ brain identity: one small bridge for the explanatory gap. *Synthese,* (in press).

Webster, W. R. (2002b),

Wavelength theory of colour strikes back: the return of the physical. *Synthese*, (in press).

Webster, W. R. (2002c),

Revelation and transparency in colour vision refuted: a case of mind/brain identity and another bridge over the explanatory gap. *Synthese*, (in press).

Webster, W. R., Crassini, B. and Willenberg, K. (1987),

Simultaneous Color Contrast from McCollough Effects is Spatially Contingent. *Perception and Psychophysics*. **41**, 402-408.

Webster, W. R., Day, R. H., and Willenberg, K. (1988),

Orientation-Contingent-Color After-effects are Determined by Real Color, not Induced Color. *Perception and Psychophysics*, **44**, 43-49.

Webster, W. R., Day R. H.,Gillies, O. and Crassini, B. (1992),

Spatial-frequency-contingent color after-effects: adaptation with two-dimensional stimulus patterns. *Perception and Psychophysics*, **51**, 66-78.

Weiskrantz, L. (1986),

Blindsight: A Case Study and Implications, Oxford University Press, Oxford.

Weisskopf, V. F. (1968),

How light interacts with matter. *Scientific American*, **219**, 60-71.

Westphal, J. (1984),

The Complexity of quality. *Philosophy*, **59**, 457-471.

Westphal, J.(1987),

Colour: Some Philosophical Problems from Wittgenstein. Oxford: Basil Blackwell.

Westphal, J.(1989),

Review of Color for Philosophers: Unweaving the Rainbow. By C. L. Hardin. *Mind*, **158**,145-146.

Westphal, J. (1991),

Colour: A Philosophical Introduction, Oxford: Basil Blackwell.

Willmer, E. N. (1946

Retinal StructureStructure and Colour Vision. Cambridge: Cambridge University Press

Wilson, M. H. and Brockelbank, R. W. (1962),

The phenomenon of coloured shadows and its significance for colour perception. *Die Farbe,* **2**, 143-146.

Wilson H. R. (1991),

Shadows on the cave wall: philosophy and visual science [1]. *Philosophical Psychology,* 4, 65-78.

Wittgenstein, L. (1978),

Remarks on Colour. (ed. G. E. M. Anscombe, trans Linda L. McAlister and Margarete Schattle, Oxford: Blackwell.

Wright, E. (1993),

New Representationalisms. Newcastle upon Tyne, Athanaeum,.

Wright, W. D. (1961-2),

Colour and its measurement, *CIBA Review, Manchester,* p 2-24.

Wright, W. D. (1946),

Researches on Normal and Defective Colour Vision. London: Henry Kimpton.

Wright, W. D. (1959),

Colour vision: a field of unsolved problems. *New Scientist,* **6** , 447-449.

Yablo, S. (1999),

Concepts and consciousness. *Philosophy and Phenomenological Research.* **LIX**, 455-463.

Yoshida, R. M. (1977),

Reduction in the Physical Sciences. Halifax: Dalhousie University Press.

Yoshioka T. and Dow, B. M. (1996),

Color, orientation and cytochrome oxidase reactivity in areas V1, V2 and V4 of macaque monkey visual cortex. *Behavioural Brain Research,* **76**, 71-88.

Yoshioka, T., Dow, B. M. and Vautin, R. G. (1996),

Neuronal mechanisms of color categorization in areas V1, V2 and V4 of macaque monkey visual cortex. *Behavioural Brain Research,* **76** , 51-70.

Young, R. A. (1977),

Some observations on temporal coding of color vision: psychophysical results. *Vision Research,* **17**, 957-965.

Young, R. A. (1987),

Color vision and the retinex theory. *Science,* 238, 1731-1732.

Zeki, S. (1983),

Colour coding in the cerebral cortex: the reaction of cells in monkey cortex to wavelengths and colours. *Neuroscience,* 9,741-765.

Zeki, S. (1990),

A century of cerbral achromatopsia. *Brain,* **113**, 1721-1777.

Zrenner,E. (1985),

The zero signal detector. in (T. Ottoson andS.Zeki eds.) *Central and Peripheral Mechanisms of Colour Vision,* London: MacMillan, pp.165-182.

Zrenner, E., Abramov, I., Akita, M., Cowey, A., Livingstone, M. & Valberg, A. (1990),

Color perception: retina to cortex. In (L. Spillman & J. S. Werner, eds.) *Visual Perception: the Neurophysiological Foundations,* San Diego: Academic Press, pp. 163-204.

NOTES

(1) (McGilvray, 1983, 1994; Hardin,1988; Campbell, 1993; Lund,1994; Tolliver,1994; Maund, 1995 ; Thompson,1995; Clark,1996; Dedrick,1996; Hall,1996).

(2) Armstrong (1993), however, rejects Campbell's Lockean theory. He says "I reject such theories. I do not think that being red is to be analysed in terms of ' the categorical basis of the disposition to make something look red' (Campbell) " (p.270).

(3) Thompson et al. (1992) and Thompson (1995) propose a relational structure for colour. They are ecological enactivists. They claim that the objectivists about colour are wrong—colours aren't out there in the world. Also subjectivists are wrong—colours aren't in the head. Where are they then? They argue for an relational view of colour in that being coloured is a relation between an animal and a spectrally selective feature of an animal environment. i.e. colours are properties of pairs of classes of organisms and classes of ecologically specified external things. Thus colours are a relation produced by the activity of organisms with the environment. This comparative view is interesting but as McGilvray (1996) points out "it provides no clear answer to the question of what is colored" (p.85).

(4) Nassau (1983) lays great emphasis on the energy of photons, which is the important characteristic of light that interacts with the energy levels of electrons. Nassau (1983) points out that spectral colours can be designated in three ways "frequency in hertz (that is, vibrations per second), wavelength in nanometres (nm) and energy in electron volts (eV) "(p.30). There is a conversion between eV and nm since eV is inversely related to wavelength, but wavelength has become the international mode of referring to colour, even though energy appears to have a number of explanatory advantages (Nassau, 1983).

(5) Tolliver (1994) argues that "The conclusion that these facts suggest is that color of a thing is not identical to any of its microstrucrural properties " (p. 417). He discusses this problem in connection with Alexandrite, which, as Nassau (1983) shows, it has two colours. The gemstone Alexandrite has the same impurity (chromium) as ruby and emerald, however, "the strength of the ligand field is about 2.17 eV, intermediate between the 2.23 of ruby and the 2.05 of emerald and the spectrum is also intermediate .... The resulting appearance is quite unexpected: in blue-rich daylight... we see an intense blue-green color, somewhat resembling emerald,...in light from an incandescant lamp we perceive a deep red color, somewhat resembling a ruby " (Nassau, 1983, p.89). The differences in illumination energy interact with the microstructure to produce different wavelengths, and thus supporting our thesis about colour.

I would like to thank Frank Jackson and John Bigelow for their encouragement and for reading and commenting on drafts of this thesis.