Colour in the Scientific Image

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Abstract

Do colours exist or are they merely an illusion? The posing of colour as a challenge to our habitual belief in the reality of the visual world is commonly thought to stem back to the so-called scientific revolution of the 17th century. Between the wars of the last century historians and philosophers like Burtt, Husserl and Whitehead gave us highly influential narratives in which the mathematized and mechanical physical sciences of Galileo and Newton (amongst others) formed a new metaphysical picture that stripped colours away from objective nature.

In this lecture I reconsider the narrative, suggesting that the puzzle of fitting colour into the scientific image really took shape in the 19th century, with the appearance of a mechanistic science of the brain and nervous system. In 1872 the pioneering neurophysiologist Emil du Bois-Reymond lectured on the "limits of our knowledge of nature". He spelled out the problem of the impossibility of a scientific understanding of conscious experience, one which philosophers of mind still grapple with today. As I will argue, the questioning of the reality of colour is one pathway towards this infamous "explanatory gap." In the 19th century, which was a great age for unificatory projects in the natural sciences, the methodological concerns of neurophysiologists became yoked to the conception of mind which we rely on to account for visual

experience. Hence, we might say, colour and the brain became mutually inexplicable.

0. Introduction

"Do colours exist or are they merely an illusion?"
This is the typical, useless, philosophical question.
Just like the questions, "Is there an external world, does *anything* exist?"

Science, unlike philosophy, deals with tractable questions that have factual answers. Abstract philosophical speculation about what does and doesn't exist has been made redundant by the natural sciences. The physical sciences can tell us what is there in the world around us – whether properties like colour exist; and the sciences of the mind, psychology and neuroscience, can inform us about when, and under what conditions, our senses lead us into the traps of illusions. End of story.

If this really were the end of the story, mine would be a very short lecture. As you must be already guessing, I don't believe this story and I don't think you should either. There's a line of thought that says we should take the philosophical problem of colour seriously because it gets to the heart of the metaphysical commitments of modern science as it emerged in the 17th century. The mathematical and mechanical worldview of modern physical sciences have pushed colour out of reality. Great physicists like Galileo and Newton *created* the problem of colour. Therefore science itself can't answer the questions about the reality of colour.

Alfred North Whitehead was one early 20th century philosopher who framed the problem in this way. Following his seminal work with Bertrand Russell, the *Principia Mathematica,* he turned his attention to metaphysics and the history of ideas. This is how he frames the issue in his book, *Science and the Modern World,* originally a series of lectures given in 1925.

> "But whatever theory [of light] you choose [i.e. wave or corpuscular],-there is no light or colour as a fact in external nature. There is merely motion of material. Again, when the light enters your eyes and falls on the retina, there is merely motion of material. Then your nerves are affected and your brain is affected, and again this is merely motion of material." (Whitehead 1938:69)

Whitehead continues:

> "But the mind in apprehending also experiences sensations which, properly speaking, are qualities of the mind alone. These sensations are projected by the mind so as to clothe appropriate bodies in external qualities which in reality do not belong to them, qualities which in fact are purely the offspring of the mind. Thus nature gets credit which should in truth be reserved for ourselves: the rose for its scent; the nightingale for his song; and the sun for his radiance. The poets are entirely mistaken. They should address their lyrics to themselves, and should turn them into odes of self-congratulation on the excellency of the human mind. Nature is a dull affair, soundless, scentless, colourless; merely the hurrying of material, endlessly, meaninglessly.
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> However you disguise it, this is the practical outcome of the characteristic scientific philosophy which closed the seventeenth century." (Whitehead 1938:70)

I endorsed that account in my book on the philosophy of colour, *Outside Color.* Nowadays I am skeptical about what I wrote there and the purpose of this lecture is to present a revised historical narrative about the emergence of

philosophical concerns about the existence of colour. I will place the blame not with physics but with the physiology of the brain and nervous system; our historical focus will not be on the 17th century but instead we'll stay a little closer to the present in the 19th century. But before moving on the 19th century I'll first say more about the philosophical problems of colour, and how they seemed to take a grip on the intellectual imagination with the so-called scientific revolution of the 17th century.

1. The Two Images

Look around and open your eyes. Open your ears. Attend to any smells and whatever tactile experiences you may feel. Physical reality appears to us full of things replete with sensory qualities: the murmur of ambient sounds, the faint odour of the air you inhale, the grey, blue or black of the sky. This is the *manifest image*. In everyday life your actions reveal your complete faith in the reality of the manifest world. Your life literally depends on the evidence of colours, smells and tastes, that the chemicals in your food and drink are nutrients and not poisons.

However, if we ask a chemist to analyse the constituents of what's on your plate no report will be given of any of these qualities. Your food consists only of long chains of complex organic molecules, sprinkled with inorganic minerals and additives. Chemical analysis might be a more reliable way of detecting traces of poisons than the crude results of our senses, but it does rather take the pleasure out of eating: no inviting colours, no enticing scents and absolutely no delicious savours. The *scientific image* of your meal is absolutely unlike the manifest one.

The mid 20th century American philosopher, Wilfrid Sellars introduced the terminology of the clash of the manifest[1] and scientific images, and encouraged us to trace the origin of the conflict back to the 17th century.

> "It is familiar fact that those features of the manifest world which play no role in mechanical explanation were relegated by Descartes and other interpreters of the new physics to the minds of the perceiver. Colour, for example, was said to exist only in sensation; its *esse* to be *percipi.*[2] It was argued, in effect, that what scientifically motivated reflection recognizes to be states of the perceiver are conceptualized in ordinary experience as traits of independent physical things, indeed that these supposed independent coloured things are actually conceptual constructions which ape the mechanical systems of the real world." (Sellars 1963:29)

This is the all too familiar narrative: the rise of the mechanical view of nature (of which Descartes' natural philosophy is exemplary) rested on the distinction between primary and secondary qualities. The primary qualities are properties of bodies which can be measured and quantified, and which feature in mechanical explanations of phenomena such as chemical reactions, the collisions of bodies, and the propagation of light. These are shape, motions, mass and texture. In contrast, the secondary qualities are tactile sensations (heat, coolness, abrasion), tastes, sounds, smells and colours. Useless to mechanical explanation and to the mathematization of our world picture, they

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[1] In Sellars (1963), the "manifest image" refers to the theoretical heritage of Western philosophy, as it evolved independently of science, from the Ancient Greeks onwards. However, in contemporary philosophy of perception, the "manifest" is used to refer just to the world as it appears to the five senses. My use of the term in the paragraphs above is more in line with this recent use.

[2] I.e. 'its existence lies in its being perceived.' This is an allusion to the idealism of Bishop Berkeley (1685-1753) – that all objects are ideas in the minds of perceivers.

are stripped from the external world of physics and given a new location in the subjective space of the mind.

It is interesting that Sellars introduces these views as "familiar fact" because this is not the account which we find in the 17th century authors themselves (more on them in a moment). Yet it was a standard reconstruction of their views amongst 20th century historian of philosophy. Along with Whitehead's *Science and the Modern World*, other key texts here are E. A. Burtt's *The Metaphysics of Modern Science* (first published in 1924), Edmund Husserl's *Crisis of European Sciences* (written 1934-7)[3], and Alexandre Koyré's *From the Closed World to the Infinite Universe* of 1939.

Lorraine Daston observes a shared elegiac theme in all of these works: a sense of loss for the innocence of the pre-modern, pre-scientific worldview.[4] The idea is that back in the middle ages there was no reason to disavow any naïve belief in the reality of the appearances generated by our senses. The alignment between sensory experience and beliefs about reality made the pre-modern world hospitable just as the modern, scientific world is cold, colourless and alienating. The primary and secondary quality distinction is not like any usual philosophical refinement – between *universals* and *particulars*, *induction* and

[3] Hilary Putnam (1926-2016), the influential American philosopher, refers to Husserl in his diagnosis of the philosophical problem of colour. A central role is played by Galileo Galilei (1564-1642) and his development of techniques of mathematical abstraction for the representation of nature. Our metaphysical quandary, Putnam writes, stems from "Objectivism… the great 17th-century project of trying to turn physics into metaphysics" (1987:29).

[4] See Daston (1991:522): "Burtt's thesis was, in a nutshell, that it was the primary/secondary quality distinction that had brought us to this regrettable pass, and that seventeenth-century thinkers such as Kepler, Galileo, Descartes, Boyle, and Newton had swallowed this unsavory doctrine in order to make the world safe for mathematized science."

deduction – it is a tearing of the very fabric of perceived reality. For instance Burtt (1932/2003:18) writes that,

> "[In the Middle Ages] The entire world of nature was held not only to exist for man's sake, but to be likewise immediately present and fully intelligible to his mind."

In this passage from David Chalmers, an influential figure in philosophy of mind today, this theme has a mythological status, where Burtt's Middle Ages becomes a pre-lapsarian paradise:

> "In the Garden of Eden, we had unmediated contact with the world. We were directly acquainted with objects in the world and with their properties….
>
> When an apple in Eden looked red to us, the apple was gloriously, perfectly and primitively *red.* There was no need for a long causal chain from the microphysics of the surface through the air and brain to a contingently connected visual experience. Rather, the perfect redness of the apple was simply revealed to us…. Eden was a world of perfect color. But then there was the Fall." (Chalmers 2006:49)

As Chalmers tells us, we ate first from the "Tree of Illusion," and then from the "Tree of Science"

Compelling as this narrative has been to many 20th and 21st century historians and philosophers (including myself), it must now be scrutinized. Lorraine Daston (1991) argues that the epistemological anxieties which we associate with the primary/secondary quality distinction were simply not there in the Early Modern texts.[5] A popular mis-reading of secondary qualities in these texts is as purely *mental.* This is Bishop Berkeley's interpretation, but

[5] In particular, Daston (1991) takes issue with Burtt's conflation of mathematized and mechanical natural philosophy See Baker *et al.* (2015) and Meli (2011) for recent work on the epistemological status of colour in early modern natural philosophy.

he does this in order to argue for a generalised idealism – there is no matter and everything is in the mind. Two 17th century writers who popularised the primary/secondary distinction, John Locke (1632-1704) and Robert Boyle (1627-1691), present it in the context of matter theory, not theory of mind. The idea is that the "corpuscles" (atoms) which they believe make up all matter have the primary qualities – motion/rest, size, shape, and they come in special arrangements, "textures". These primary qualities give matter the power or disposition to affect our sensory organs in special ways.[6]

At that time – but not now – it remained an open scientific possibility that there would be just one particular arrangement of primary, physical qualities that could be associated with each specific shade of colour, such that our experience of orange, say, just presents a corresponding objective physical property to us. An interesting case in point occurs in Boyle's *Experiments and Considerations Touching Colours* of 1664. An anecdote is reported about a blind man from the low countries who is able to distinguish the colour of ribbons by using his sense of touch. Boyle entertains it as an open possibility that the particular textures associated with black, white, yellow, etc., might be discernible by this individual because his tactile sensitivity is more acute than in the sighted.

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[6] E.g. Boyle in the *Origin of Forms and Qualities According to the Corpuscular Philosophy* of 1666 writes:

"these sensories may be wrought upon by the figure, shape, motion and texture of bodies without them after several ways, some of those external bodies being fitted to affect the eye, others the ear, others the nostrils, &c. And to these operations of the objects on the sensories, the mind of man, which upon the account of its union with the body perceives them, giveth distinct names, calling on *light* or *colour,* the other *sound,* the other *odour."* (Boyle 1979:31)

Note also that the notion the term "disposition" was used ambiguously in the 17th century to refer either to a tendency of an object to modify light or to a power to produce a certain sensory experience (Adams 2016:96 fn24).

Even René Descartes (1596-1650), who in his *Meditations on First Philosophy* speaks quite negatively about the senses as confused and potentially deceptive does tell us that there is a firm physical basis for colour experience. Colour sensations are caused by particular motions of the particles constituting light beams, which have a determinate effect on the motions of the optic nerve fibres. In his *Optics* of 1637 Descartes tells us that:

> "regarding light and colour...we must suppose our soul to be of such a nature that what makes it have the sensation of light is the force of the movements taking place in the regions of the brain where the optic nerve-fibres originate, and what makes it have the sensations of colour is the manner of these movements." (Descartes 1985, 167)

However, he insists, "there need be no resemblance between the ideas which the soul conceives and the movements [of the nerves] which cause these ideas" (Descartes 1985, 167). Sensations are *signs* for external objects, mediated by the code of activations in the nerves; as with communication via Morse code, the blips of the signal, the object signified, and the word invoked in mind of the perceiver bear no likeness with one another.

In *An Essay Concerning Human Understanding* (first published in 1689), Locke points out that it is incomprehensible to us how particular kinds of primary qualities can bear any relation to the sensory ideas that they cause in us.

> "We are so far from knowing *what* figure, size or motion of parts produce a yellow colour, a sweet taste or a sharp sound, that we can by no means conceive how *any* size, figure or motion of any particles, can possibly produce in us the idea of any colour, taste or sound whatsoever: there is no conceivable connexion between one and the other." (Locke 1700/1975: IV.iii.13, p. 545)

Locke puts this down to "the arbitrary will and good pleasure of the Wise Architect." This passage is quoted by the contemporary philosopher Barry Stroud (2000: 88-89) in order to highlight the lack of a "satisfying natural explanation" of sensory experience.[7] However, this presupposes an opposition of naturalistic and theistic science which is itself only constructed in the 19th century. So when Locke invokes God in the context of offering a mechanical explanation of sensory experience, we should not interpret Locke as pointing out an "explanatory gap" here. We cannot assume that the shift from mechanical to theistic explanation stuck out for Locke in the way that it does for us now.[8]

What we can say is that the innovators in the mechanics and optics of the 17th century did sometimes make declarations which prompt questions about the reality of colour. Descartes was one such thinker. Galileo and Newton were others. Here is Newton, in the *Optics* discussing the famous prism experiments:

> "And if at any time I speak of Light and rays as coloured or endued with Colours, I would be understood to speak not philosophically and properly, but grossly, and accordingly to such Conceptions as vulgar People in seeing all these Experiments would be apt to frame. For the Rays to speak properly are not coloured." (Newton 1704/1952:124–25)

And this passage from Galileo's *The Assayer* of 1623*,* is quoted by various contemporary philosophers writing on colour:

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[7] Cf. Putnam (1987 p.8) "An 'explanation' that involves connections of a kind we do not understand at all ….. and concerning which we have not even the sketch of a theory is an explanation through something more obscure than the phenomenon to be explained."

[8] Note, however, that Locke's position here was contrary to Leibniz's (1646-1716) theology where it is presumed that, "God would not create a world with completely brute and inexplicable connections in it" (Duncan: 2012:258).

> "Hence I think that these tastes, odours, colours, etc., on the side of the object in which they seem to exist, are nothing else than mere names, but hold their residence solely in the sensitive body; so that if the animal were removed, every such quality would be abolished and annihilated. Nevertheless, as soon as we have imposed names on them, particular and different from those of the other primary and real accidents, we induce ourselves to believe that they also exist just as truly and really as the latter." (trans. in Burtt 1932/2003:85) [9]

However, just because we find that these passages reflect our own anxiety about the reality of colour it does not mean that these worries were felt, centuries ago, in the same way. It is easy to see in the past a mirror of the present. It is in more recent – but paradoxically less well known – history that we find a truer likeness to ourselves. And, to put my new account in a nutshell, the problem of colour arises precisely when research is being directed at producing mechanistic explanations for mental capacities – not only perceiving and sensing, but also thinking and acting.

2. Colour and Mind in the Scientific Image

The idea that there was a specific, world-changing event, the "scientific revolution", that occurred in the 16th and 17th centuries is the assumption that gave rise to my academic discipline, history and philosophy of science, in the mid 20th century. The interesting thing is that few experts now think that such

[9] Boghossian and Velleman (1989, 81), Thompson (1995, 19), Hilbert (1987, 3), and Giere (2006, 23). For recent, historically sensitive readings of Galileo see Buyse (2015) and Baker (under review).

a clearly circumscribed event ever happened.[10] For one thing, the word "science" only took up its current English meaning in the 19th century, and it was then that its recognisable institutional structures came into being.

Interestingly, we owe the narrative of the pre-eminence of the 17th century at least in part to this period. For I should mention in passing now that two 19th century "men of science" who will shortly be the focus of our attention, Thomas Huxley and Emil du Bois-Reymond, were keen to attribute their own conception of the reflexes of the nervous system to Descartes.[11] Roger Smith (2016:10) notes the long reach of the 19th century into 20th century writing on philosophy and the history of science, characterising A. N. Whitehead and E. A. Burtt as "late Victorians" in their intellectual outlook. For instance, Whitehead writes:

> "A brief, and sufficiently accurate, description of the intellectual life of the European races during the succeeding two centuries and a quarter up to our own times is that they have been living upon the accumulated capital of ideas provided for them by the genius of the seventeenth century." (Whitehead 1938:53)

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[10] Shapin (1996:1) begins "There was no such thing as the Scientific Revolution, and this is a book about it"; see the bibliographic essay (pp.168-170) for comprehensive references on the traditional account of the scientific revolution. Hatfield (1990) gives a detailed criticism of the view of Burtt, and others, that the advances of the 17th century yielded coherent metaphysical worldview. In the 18th Dibner Library Lecture, "The Philosophical Breakfast Club & The Invention of the Scientist," Laura Snyder presents the view that the 19th century was crucial to the formation of modern science.

[11] Canguilhem (1955/2015:139-142) on du Bois-Reymond. Canguilhem notes his tendency to attribute scientific advances to historical figures like Descartes who were avowed mechanists rather than giving credit to discoveries made by researchers who espoused non-mechanist ideas. Furthermore, Du Bois-Reymond (1882:442) states that Gottfried Leibniz (1646-1716) had a mechanical conception of the physical world "quite the same as" his own, the difference being that Leibniz also posited the existence of the spiritual in addition to the material (cf. du Bois-Reymond 1879).

This standard narrative, while so boldly stated, is still popular amongst philosophers concerned with the history of ideas, but largely disputed by historians.[12] In my account I agree with Burtt and Whitehead that the problem of colour comes to philosophical prominence with the birth of modern sciences. The difference is that I date the relevant birth two centuries after they do. The scientific developments crucial to the problem were ones happening in the life and mind sciences: physiology, biology and psychology, and where physics has a role in our story it is not mechanics, or mathematical methods in general, but the discovery of the law of conservation of energy (van Strien 2015).

I will focus in particular on three men whose thought is far less familiar to philosophers today than that of the early moderns discussed above. However, all three were extremely influential in the world of ideas in their own time. They are Thomas Henry Huxley (1825-1895), the comparative biologist and populariser of evolutionary theory, known as "Darwin's bulldog"; the "synthetic" philosopher and evolutionary theorist Herbert Spencer (1820-1903) and the neurophysiologist Emil du Bois-Reymond (1818-1896). Needless to say, my selection is somewhat arbitrary. Perhaps I could have just as well chosen Hermann von Helmholtz (1821-1894), the psychophysicist and philosopher Gustav Fechner (1801-1887), and the neurologist John Hughlings Jackson (1835-1911), or many others. My discussion is not intended to give you the definitive chronicle of all the talk of the status of mind and colour in the late

[12] Here is an illustration of this disciplinary difference. The title of philosopher A. C. Grayling's (2016) book, *Age of Genius: The Seventeenth Century and the Birth of the Modern Mind* is perhaps an echo of Whitehead's "Century of Genius", the title of the chapter from which the last quotation is taken. A rather critical review by historian Thomas Colville (2017) raises the typical objections to the "late Victorian" approach in intellectual historiography.

19th century, but it should at least convince you that this is a period worth looking into.[13]

2.1 Herbert Spencer

Spencer is now best known for his criticism of government intervention, and for coining the phrase "survival of the fittest".[14] In 1855 he published his first major work, the *Principles of Psychology.* It has more in common with speculative metaphysics than the evolutionary biology and experimental sciences that would later influence his thought. I bring it up to show how discussion of the primary/secondary distinction has migrated from physical science to the study of mind. Spencer presents a tripartite distinction which he credits to the Scottish metaphysician Sir William Hamilton.[15]

In Spencer the secondary qualities are rebranded as "dynamical attributes". The important point is that these are in no way *mental* properties; they are entirely physical but have their origins in the forces, rather than the objects around us.

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[13] Note that I have entirely neglected scientific work and the world of ideas beyond Britain and Germany. For more widely ranging accounts of the conceptual development of neurophysiology see e.g. Canguilhem (1955/2015) *La Formation du Concept de Réflexe* and Smith (1992) *Inhibition.*

[14] For overviews on the biological and psychological ideas of Spencer see Richards (1987) *Darwin and the Emergence of Evolutionary Theories of Mind and Behavior;* Taylor (2010) *The Philosophy of Herbert Spencer;* and Francis (2014) *Herbert Spencer and the Invention of Modern Life*.

[15] For our purposes we will ignore his third category of "statico-dynamical attributes". See Smith (2016: 89-93) for background to the theories of muscular sense and touch which shaped discussions of objectivity at this time. See Hamilton (1853, Chapter 5) "Distinction of the Primary and Secondary Qualities of Body" for an in depth historical analysis of the distinction, which diverges from the account later popularized by Burtt and Whitehead. I thank Tawrin Baker for bringing this text to my attention.

> "it becomes an unavoidable conclusion that those properties of things which we know as tastes, scents, colours, temperatures, sounds, are effects produced in us by forces in the environment. The subject undergoes a change of state, determined in him by some external agency directly or indirectly proceeding from an object….. In respect to all these so-called secondary attributes, the object is *active* and the subject is *passive*. Or, in other words, they are *dynamical* attributes." (Spencer 1855:194-5)

These dynamical attributes do not present any distinct epistemological or ontological challenges: they are as easily known as any other physical attributes,[16] and can be fitted without trouble into a world picture which consists of matter and forces. Spencer does not think of primary properties – now called "statical attributes" – as in any way more objective than the secondary/dynamical ones. In fact, the opposite. He argues that activity on the part of the perceiver is required for the perception of primary/statical attributes, namely size, shape and position in space.[17] This is because we perceive these properties via the modality of touch, and this sense requires

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[16] One small qualification: the dynamical/secondary attributes, conceptualised as properties of objects, not forces, are "occult" (i.e. hidden):

> "To an uncritical observer, the visible outlines of an object will perhaps seem to be as much thrust upon his consciousness by the object itself, as its colour is. But on remembering that these visible outlines are revealed to him only through certain modifications of light; that these modifications are produced not by the outlines, but by certain occult properties of the substance having these outlines; and that were these occult properties absent the outlines would be invisible; it will be seen that the outlines are known not immediately but mediately." Spencer (1855:218-9)

[17] "In respect of its space-attributes – Bulk, Figure, and Position – body is altogether passive: and the perception of them is wholly due to certain mental operations, certain acts of thought. Unlike heat, sound, odour, &c., of which we become conscious by the union of our own acts with the acts of things; the phenomena of extension in their several modifications, are cognizable entirely through an internal co-ordination of impressions: a process in which the extended object has no share." (1855:218)

that we move our body – running our hand along the edge of a table, for example.[18]

Putting the finer points of Spencer's account aside, the important lesson for us is that even as late as the middle of the 19th century, colours were not taken to be unreal, and not necessarily more subjective than the primary properties of size, shape and position. According to Daston and Galison (2007:273), a change occurs so that, "[b]y the late nineteenth century, color had become a paradigmatic example of private, incommunicable subjectivity." Their explanation for this shift is that it comes about with the experimental psychology and physiology of colour experience. Goethe's theory of colours – *Zur Farbenlehre*, published in 1810 – distinguishes subjective colour effects, originating in the eye, with objective ones due to the external light source (Daston and Galison, 2007:277).[19] The subjective effects come under the increasing scrutiny of scientists such as Helmholtz, J. Purkinje and Ewald Hering. Also, colour blindness and other kinds of variation in colour perception are increasingly recognised and studied. .

So colours pass from being anchored in objective physical stimuli to being thought of as no more than subjective effects of nervous stimulation, literally there in the eye of the beholder. Thus the location of colour in the scientific image has been shunted from the objective domain of physics to the subjective one of psycho-physiology. That is not to say that this placed colour in a

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[18] Another interesting departure from previous versions of the primary/secondary distinction is that most of the time Spencer claims that primary/statical attributes are not *common sensibles* (i.e. properties available to more than one modality) but that they are known only through touch (Spencer 1855:215 and 219-221).

[19] Note also that Goethe is one highly influential source of the idea that 17th century, mechanistic science, culminating with Newton, stripped colour and meaning from nature. The purpose of Goethe's research on colour was in fact to refute the Newtonian worldview. See Harrington (1996:4-6).

scientific backwater. On the contrary, physiology was a high-profile, high-technology discipline at the time, and discussion of it attracted much popular attention (Brain 2015:xv).

2.2 T. H. Huxley – Conscious Sensations as By-Product

T.H. Huxley was one of the most influential popularisers of the biological sciences. A comparative zoologist, geologist, essayist and polemicist, his (and his allies) delineation of naturalistic, as opposed to theistic, science shaped the conception of science still employed in the English-speaking world.[20] While Huxley did not perform neurophysiological experiments himself, the findings of others influenced him deeply in his writings on naturalistic explanations of the mind, which in turn had a lasting impact on the philosophy of mind via the discussion of William James and others. In the last three decades of the 19th century, the "paradigm" for research in neurophysiology was reductionist and mechanist. These two aspects are given full voice in Huxley's writing on the topic.

Firstly, like du Bois-Reymond, who we will turn to in a moment, Huxley is convinced of the unique power of reductive explanation. By this I mean the reliance of decomposition of a chemical compound, or a biological system, into its simpler working parts or constituents, and accounting for the properties and behaviour of the whole in terms of the powers and actions of the parts. Thus Huxley writes,

> "we live in the hope and in the faith that, by the advance of molecular physics, we shall by-and-by be able to see our way as clearly from the

[20] See Stanley (2015) *Huxley's Church & Maxwell's Demon* and White (2002) *Thomas Huxley : Making the 'Man of Science.'*

constituents of water to the properties of water, as we are now able to deduce the operations of a watch from the form of its parts and the manner in which they are put together." (Huxley 1870:25)

Huxley then transfers the idea of reductive explanation from inorganic chemistry to the chemical basis of life:

> "Is the case in any way changed when carbonic acid, water and ammonia disappear, and in their place, under the influence of preexisting living protoplasm, an equivalent weight of the matter of life makes its appearance?" (Huxley 1870:25)

It is telling that Huxley, the antagonist of clergymen and arch opponent of any religious influence in natural science, the "agnostic" over all matters of metaphysics and divinity, places "hope" and "faith" in the future potential of reductive explanation. While this choice of words may be a mere rhetorical flourish, a deeper lesson to take from this passage is the connection between reductive and mechanistic explanation: the prime example of clear reductive understanding is the knowledge we can have of a man-made mechanism – a watch – by seeing the workings of its parts.

Huxley called physiology "the mechanical engineering of living machines" (Stanley 2015:197). Living at a time in which steam power had been the engine of unprecedented material changes, it should not surprise us that steam engines, alongside the clock-work marvels of Enlightenment Europe,[21] are the go-to technologies to which he compares the biological machines studied by physiologists.

[21] Huxley (1875) pays passing tribute to Jacques de Vaucanson (1709-1782), master inventor of clockwork automata.

> "A living body is a machine by which energy is transformed in the same sense as a steam-engine is so, and all its movements, molar and molecular, are to be accounted for by the energy which is supplied to it." (Huxley "The Progress of Science", quoted in Stanley 2015:200)

There is an extrapolation from the law of conservation of energy to the mechanistic idea that the forces and laws governing biological organisms are all the same as those operative in the non-living world. Nothing in the physics of conservation of energy entails this conclusion, even though this is often supposed (Papineau 2001), and this extrapolation was encouraged by physicist and psycho-physiologist Hermann von Helmholtz in his exposition of his discoveries regarding conservation (Helmholtz 1854:182-3).

The agenda of Huxley's well-known lecture, "On the hypothesis that animals are automata, and its history" (1875),[22] is to convince us of a triumphalist story in which the physiology of the day is the culmination of the mechanistic insights had by Descartes, and others, at the dawn of modern science:

> "in the seventeenth century, the idea that the physical processes of life are capable of being explained in the same way as other physical phenomena, and, therefore, that the living body is a mechanism, was proved to be true for certain classes of vital actions; and, having thus taken firm root in irrefragable fact, this conception has not only successfully repelled every assault which has been made upon it, but has steadily grown in force and extent of application, until it is now the expressed or implied fundamental proposition of the whole doctrine of scientific Physiology." (Huxley 1875:49)

[22] Presented at Belfast to the British Association for the Advancement of Science in 1874.

It follows, then, that the seemingly purposive and thoughtful behaviour of animals might be entirely accounted for as the operation of complex, deterministic, *reflex mechanisms*. While Descartes has been read, notoriously as asserting that animals are *unconscious* automata,[23] Huxley tells us that the "doctrine of continuity" (1975:13) – i.e. that humans evolved from "lower" species – implies that animals have some degree of consciousness. So what to say about consciousness? The reductive and mechanistic explanations of such capacities as jumping, seeing, and writing a letter have no use for subjective experience. The workings of the nerve, brain and muscle machine go happily along in a closed, causal loop without the intervention of a sentient, willing mind.

Thus the sensations which we know from experience to accompany each of these activities – the decision that prompts a jump, the feeling of muscular effort – are, Huxley tells us, mere by-products of the brain-engine:

> "It may be assumed, then, that molecular changes in the brain are the causes of all the states of consciousness of brutes. Is there any evidence that these states of consciousness may, conversely, cause these molecular changes which give rise to muscular motion? I see no such evidence…..
>
> The consciousness of brutes would appear to be related to the mechanism of their body simply as a collateral product of its working, and to be as completely without any power of modifying that working, as the steam-whistle which accompanies the work of a locomotive engine is without influence upon its machinery."[24] (Huxley 1875:62)

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[23] This reading is disputed by Katherine Morris (2000) and Jessica Riskin (2016).

[24] Elsewhere in the lecture, clock-work is the technological analogue:

> "The soul stands related to the body as the bell of a clock to the works, and consciousness answers to the sound which the bell gives out when it is struck" (Huxley 1875:62-3)

This metaphor of the steam-whistle is discussed by William James (1890, chapter 5) in his attack on the "automaton-theory" and is familiar to today's students of philosophy of mind, where Huxley is interpreted – inaccurately according to Campbell (2001) and Greenwood (2010) – as espousing the "epiphenomenal" theory of the mind-body relationship, the idea that the mental states are fundamentally different from physical brain states, but are the causally inert products of the brain.[25]

Huxley has urged us to think of our conscious sensations as the by-product of our neural mechanisms. But I suggest we conclude something different: *that consciousness, after Huxley, has come to be the by-product of the mechanistic explanation of behaviour*. For the rhetorical force of Huxley's two central examples of the apparently normal reactions of a decapitated frog and a sleepwalking sergeant comes from the implication that all of our seemingly intelligent behaviour, which we presume requires awareness for successful execution, can actually go along happily without direction from the conscious mind. Furthermore, this is precisely what mechanists need to show us in order to support the claim that adaptive behaviour in biology is not made possible by special vital or psychic forces. It is a tenet of the 19th century mechanistic explanatory project that comparisons between living and non-living systems

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> "they [the 'phenomena of the senses'] are something manufactured by the mechanism of the body, and as unlike the causes which set the mechanism in motion, as the sound of a repeater is unlike the pushing of the spring which gives rise to it." (Huxley 1875:53)

A repeater is a type of watch or clock which chimes the hours at the press of a button. In every case, consciousness is compared to the sound made by a device, which itself can not make any difference to the causal workings of the machine.

[25] This is inaccurate because Huxley's official position on the mind-body relationship is one of *agnosticism*. He refused to take up substantial opinions about the fundamental nature of mind, even materialistic ones, because of his Humean scruples against metaphysical speculation. See Huxley (1870:33ff).

performing equivalent functions – such as brains, computers and counting machines – can yield complete causal explanations. It is a *presupposition*, not a discovery, of the mechanistic explanatory project that the conscious sensations which accompany the process of addition in humans (but not in counting machines) are irrelevant to the explanation of the ability to do arithmetic. In that sense epiphenomenal mentality – here the inner speech which seems subjectively necessary for the accurate tallying of numbers – is a by-product not of our cognitive brain engine, but of the late 19th century framework for mechanistic explanation of the brain.

In sum, on the heels of the late 19th century mechanist movement, of which Huxley was one figurehead, consciousness has been downgraded to the residual of mechanistic and reductive explanation: that which is left over from a complete, causal account of all of the capacities of the brain and nervous system. This is the narrow meaning of "consciousness" which is now currency in the philosophy of mind, replacing the earlier, more expansive notion of "consciousness" as an individual mind or self, along with all of the self-reflexive thoughts and experiences contained within it.[26]

Once we have defined conscious sensations as epiphenomenal steam, the by-product of advanced scientific explanation, it would seem to follow logically that any accounting for that weird mental stuff is beyond the remit of science. That is exactly the position that Huxley and our next figure, the neurophysiologist Emil du Bois-Reymond, do take.[27] But strangely enough this

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[26] See Jorgensen (2014) on the early meanings of "consciousness". Note that this author does, however, attribute the major shifts in meaning to 17th century developments. See also the introduction of Heinämaa et al. (2007) for a broad historical overview.

[27] For instance, in a frequently quoted text, Huxley tells us that:

> "How it is that any thing so remarkable as a state of consciousness comes about as the result of irritating nervous tissue, is just as unaccountable as the appearance of the Djin when Aladdin rubbed his lamp." (Huxley and Youmans 1868:178)

view invited hostility and controversy, and I now think of much of the work of contemporary philosophy of mind and perception as grappling with, and trying to resist, this apparently logical result.

2.3 Emil Du Bois-Reymond and the Limits of Our Knowledge of Nature

The surveying of the limits of science was a popular activity in the last third of the 19th century. In Britain Huxley and his antagonists in the ecclesiastical establishment debated this, as did the physicist and evangelical Christian, James Clerk Maxwell (Stanley 2015:80). The German-speaking world was undergoing rapid industrialization and social transformation,[28] and various historians have commented on the political context in Prussia that spurred such debates.[29] One intervention stands out: Emil Du Bois-Reymond's 1872

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[28] Dierig (2006) emphasizes the significance of the rapidly industrializing city of Berlin as the backdrop to du Bois-Reymond's laboratory research. Du Bois-Reymond himself remarks on the connection between sooty, coal driven technology and the recently invented power to produce brilliant colour with synthetic dyes:

> "From the black, noisome waste-products of coal-gas, which has transformed every city into another Baku, chemistry derives coloring-matters before which the splendor of tropic plumage pales" (du Bois Reymond 1878:390).

[29] E.g. Schiemann (2009:245) writes:

> "After a phase of relatively unhampered spread of extreme world schemes, in the 1870s a change in attitude seemed to occur that cannot be understood without considering the political circumstances of the times. An effort to objectify the discussion on materialism arose, aimed particularly at warding off the linking of an allegedly scientifically proven materialistic conception of nature to radical critique on capitalism. Eminent natural scientists publicly stressed that the scope of the materialistic (later monistic) conception of nature is limited, pointed out the epistemological assumptions connected to it and which alternatives were available. Besides Emil Du Bois-Reymond and Rudolf Virchow, Helmholtz participated in this critical debate, which helped counteract the growing influence of materialism on the working populace that particularly middle class circles found threatening. Within the context of the conflict between the Catholic Church and the Prussian government, namely the so-called 'cultural struggle' [*Kulturkampf*] that Bismarck initiated in 1871, the claim to

public lecture on the "Limits of Our Knowledge of Nature" ("Ueber die Grenzen des Naturerkennens"). Even though the views presented in the "Limits" were not particularly original to Du Bois-Reymond,[30] his presentation of them is particularly lively and thought-provoking.

The celebrated neurophysiologist did not retain the influence that he'd had on the world of ideas much long after his death,[31] but the declaration with which he ends that lecture "IGNORABIMUS!" ("we shall not know!") managed to enter common currency and has its own Wikipedia page. The thing that we will never know or understand is the relationship between mind and body, how the buzz of electrical activity in our brains gives rise to emotions, sensations, and all of our conscious experience:

> "Astronomical knowledge of the brain--the highest grade of knowledge we can expect ever to have--discloses to us nothing but matter in motion. But we cannot, by means of any imaginable movement of material particles,

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> exclusiveness formerly upheld by religious, spiritual and metaphysical conceptions of the world lost ground to a degree hitherto unknown. Overall interpretations of the world, which were meant to provide meaning for it all, increasingly became the private matter of each individual and just as contingent as individual existence."

See also Beiser (2014:192), Harrington (1996:13), Finkelstein (2013, chap. 12)

[30] As du Bois-Reymond (1882:433, 439) points out, noting the similarity with Leibniz's thought experiment of the thinking mill in the *Monadology* of 1714; and see Beiser (2014:102). However, Leibniz can be interpreted as arguing that because the notion of a mechanical mind is inexplicable to human reason, such minds do not exist (Duncan 2012), whereas du Bois-Reymond is saying both that our minds are in fact mechanical and that the way that their workings produce experience is inexplicable.

[31] Du Bois-Reymond's magnum opus on the electrophysiology of nerves and muscles, *Untersuchungen über thierische Elektricität* (*Investigations on Animal Electricity*) is not in print, and is not available in translation except for a condensed abstract (Jones 1852). The English translations of the philosophical and historical writings date from his lifetime. However, interest in du Bois-Reymond has recently increased. See the biography by Gabriel Finkelstein (2013); also *Müller's Lab* by Laura Otis (2007, chap. 3) and *Wissenschaft in der Machinenstadt* by Sven Dierig (2006).

bridge over the chasm between the conscious and the unconscious." (du Bois-Reymond 1874:28)[32]

This is a perfect articulation of what philosophers of mind today call the "explanatory gap" between the natural sciences and the understanding of mental experiences (Levine 1983). More poetically, du Bois-Reymond also writes:

"The dreamless sleeper is comprehensible to us, like the universe previous to consciousness. But, as, on the first awakening of consciousness, the world became doubly incomprehensible, so too is it with the sleeper, at the first appearance of a faint image in dreaming." (du Bois-Reymond 1874:29)[33]

So why does du Bois-Reymond think that consciousness is so utterly inexplicable? To answer this question we must examine his own notions of scientific explanation. For one thing, du Bois-Reymond takes the impossibility of explaining consciousness to be a result of the law of conservation of energy:

"Motion can only produce motion, or be converted back into potential energy. Potential energy can only produce motion, maintain static equilibrium, or exert pressure or traction. The sum of energy, however remains the same. Beyond this law nothing can go in the physical world, nor can any thing fall short of it; the mechanical cause passes completely into the mechanical effect. Hence the mental phenomena, which in the

[32] "Die astronomische Kenntniss des Gehirnes, die höchste, die wir davon erlangen können, enthült uns darin nichts als bewegte Materie. Durch keine zu ersinnende Anordnung oder Bewegung materieller Theilchen aber lässt sich eine Brücke in's Reich des Bewusstseins schlagen." (du Bois-Reymond 1886:122)

[33] "Der traumlos Schlafende ist begreiflich, so weit wie die Welt, ehe es Bewusstsein gab. Wie aber mit der ersten Regung von Besusstsein die Welt doppelt unbegreiflich ward, so wird auch der Schläfer es wieder mit dem ersten ihm dämmernden Traumbild." (du Bois-Reymond 1886:124)

> brain appear in company with material phenomena, are, so far as our understanding is concerned, void of sufficient basis. They lie beyond the law of causality, and hence are unintelligible…" (du Bois-Reymond 1874:28)[34]

It is worth noting that such applications of the conservation law – in particular the implication that there is no free will – were disputed by contemporary physicists James Clerk Maxwell (1882) and Ernst Mach (see Banks 2014:82).

As with Huxley, the ideals of reductionist and mechanistic explanation are predominant for du Bois-Reymond, and here given the particular incarnation of the "Laplacian Demon".[35] Laplace's Demon is a super-human intelligence who knows all of the positions of the atoms that make up the universe, has complete knowledge of the laws of nature that govern their interaction, and whose mind has the computational power to calculate how the configurations of all these atoms will evolve to predict the state of the world at any point in the future, and to rewind the calculations to know in exquisite detail any events of the past. The Laplacian Demon is the embodiment of the ambitions of reductionistic and mechanistic science because to say that the future of the whole world can be predicted by such calculations, is to say that everything

[34] "Bewegung kann nur Bewegung erzeugen, oder in potentielle Energie zurück sich verwandeln. Potentielle Energie kann nur Bewegung erzeugen, statisches Gleichgewicht erhalten, Druck oder Zug üben. Die summe der Energie bleibt dabei stets dieselbe. Mehr als dies Gesetz bestimmt, kann in der Körperwelt nicht geschehen, auch nicht weniger; die mechanische Ursache geht rein auf in der mechanischen Wirkung. Die neben den materiellen Vorgängen im Gehirn einhergehenden geistigen Vorgänge entbehren also für unseren Verstand des zureichenden Grundes. Sie stehen ausserhalb des Causalgesetzes, und shon darum sind sie nicht zu verstehen…" (du Bois-Reymond 1886:122-3)

[35] Due to the French physicist Pierre Laplace (1749–1827)

that is to happen occurs because of the smallest constituents of matter (reductionism) and their simple, clock-work like interactions (mechanism).[36]

So on this conception of science, the limits of what a near-divine Laplacian mind may know are the boundaries of all possible future science, however mind-bogglingly sophisticated and advanced.[37] And so du Bois-Reymond describes how the explanation of the arising of subjective experience from the brain is excluded from the comprehension of the Laplacian mind:

> "What conceivable connection subsists between definite movements of definite atoms in my brain, on the one hand, and on the other hand such (for me) primordial, indefinable, undeniable facts as these: 'I feel pain, or pleasure; I experience a sweet taste, or smell a rose, or hear an organ, *or see something red*,' and the immediately-consequent certainty, 'Therefore

[36] "If we were to suppose all changes in the physical world resolved into atomic motions, produced by constant central forces, then we should know the universe scientifically. The condition of the world at any given moment would then appear to be the direct result of its condition in the preceding moment, and the direct cause of its condition in the subsequent moment. Law and chance would be only different names for mechanical necessity." (du Bois-Reymond 1874:18)
"Denken wir un alle Veränderungen in der Körperwelt in Bewegungen von Atomen aufgelöst, die durch deren constante Centralkräfte bewirkt werden, so wäre das Weltall naturwissenschaftlich erkannt. Der Zustand der Welt während eines Zeitdifferentiales erschiene als unmittelbare Wirkung ihres Zustandes während des vorigen und als unmittelbare Ursache ihres Zustandes während des folgenden Zeitdifferentiales. Gesetz und Zufall wären nur noch andere Namen für mechanische Nothwendigkeit." (du Bois-Reymond 1886:106)

[37] "Thus the knowledge of Nature possessed by the mind imagined by Laplace, represents the highest thinkable grade of our own natural science. Hence we may lay this down as the basis of our inquiry as to the limits of this science. Whatever would remain unknown to such a mind, must be perfectly hidden away from our minds, which are confined within much narrower bounds." (du Bois-Reymond 1874:20)
"Das Naturerkennen des LAPLACE'schen Geistes stellt somit die höchste denkbare Stufe unseres eigenen Naturerkennens vor, und bei der Untersuchung über die Grenzen dieses Erkennens können wir jenes zu Grunde legen. Was der LAPLACE'sche Geist nicht zu durchschauen vermöchte, das wird vollends unserem in so viel engeren Schranken eingeschlossenen Geiste verborgen bleiben." (du Bois-Reymond 1886:111)

I exist?'[38] It is absolutely and forever inconceivable that a number of carbon, hydrogen, nitrogen, oxygen, etc., atoms should not be indifferent as to their own position and motion, past, present, or future. It is utterly inconceivable how consciousness should result from their joint action." (du Bois-Reymond 1874:28; emphasis added)[39]

Remember that when Locke noted the dissimilarity between the external causes and our experience of colour, he appealed to God's wisdom: such is the way of the world. For the naturalistic scientist, there can be no appeal to Divine workings -- we have a brute, inexplicable fact. At the very place where the early moderns saw reason to posit God's orchestration – the passage from material to mind – the 19th century moderns like Huxley and du Bois-Reymond found only atoms and emptiness. Hence, the union of body and soul has become, two hundred years later, an explanatory void for the naturalistic project.[40]

Remember also that through the work of Helmholtz and others on trichromacy and variation in colour vision, colours came to be seen more as subjective than objective phenomena. Here the problem is that such subjective sensations arise inexplicably from the matter of the brain without

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[38] Apparently an allusion to the *cogito ergo sum* in Descartes' *Meditations.*

[39] "Welche denkbare Verbindung besteht zwischen bestimmten Bewegungen bestimmter Atome in meinem Gehirn einerseits, andereseits den für mich ursprünglichen, nicht weiter definirbaren, nicht wegzuleugnenden Thatsachen: 'Ich fühle Schmerz, fühle Lust; ich schmecke Süsses, rieche Rosenduft, höre Orgelton, sehe Roth,' und der ebenso unmittelbar daraus fliessenden Gewissheit: 'Also bin ich'? Es ist eben durchaus und für immer unbegreiflich, dass es einer Anzahl von Kohlenstoff-, Wasserstoff-, Stickstoff-, Sauerstoff- u. s. w. Atomen nicht sollte gleichgültig sein, wie sie liegen und sich bewegen, wie sie lagen und sich bewegten, wie sie liegen und sich bewegen werden. Es ist in keiner Weise einzusehen, wie aus ihrem Zusammensein Bewusstsein entstehen könne." (du Bois-Reymond 1886:123)

[40] In a subsequent lecture du Bois-Reymond (1882: 440) explicitly parts company with Leibniz in accepting that the mind has a material basis, and thereby rejecting Leibniz's explanation of consciousness as due to God arranging creation so that experiences in the soul occur in tandem with arrangements of matter (the thesis of *pre-established harmony*).

neurophysiology giving us (or ever being able to give us) a hint or a clue as to how that may be. The philosophical problem of colour has now been sewn up with the problem of the relationship between brain and mind, and both alike are slung into du Bois-Reymond's explanatory chasm.

Needless to say, "Ignorabimus" was not the last word on the matter. Many were shocked by the confession, from Du Bois-Reymond – such a prominent advocate for the physical-mechanical vision of life – that he thought scientific knowledge had any limits at all. Not only did he strike a defeatist note on our understanding of consciousness, but he also claimed the intrinsic nature of matter itself to be beyond our intellectual reach. Numerous intellectuals entered the public debate in order to cut through the bounds with which Du Bois-Reymond had tried to confine the ambitions of science.[41]

Thus the Ignorabimus-Streit was one of the defining intellectual controversies of its time, sending ripples into the 20th century philosophy of Ludwig Wittgenstein and Rudolph Carnap. For all that, du Bois-Reymond's lecture never entered the curriculum of philosophy of mind; yet, more than any other text I know, it defines the working agenda for the subject today, and formulates the concepts of experience and sensation that we are still struggling to work with.

Before concluding it is worth mentioning some of the various responses that the mystery of the connection between brain and mind elicited at the

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[41] Some papers central to the controversy are collected in *Der Ignorabimus-Streit*, edited by Bayertz, Gerhard, and Jaeschke (2012). See also Beiser (2014, chap. 3) . For du Bois-Reymond's reflections on the controversy, see his lecture of 1880, "The Seven World Problems" (1882 *Popular Science Monthly*)/"Die sieben Welträthsel" (1886 in *Reden*).

time.[42] The advice of neurologist Hughlings Jackson, writing in the 1870's, is that we should bracket the problem as irrelevant to medical science:

> "We cannot understand how any conceivable arrangement of any sort of matter can give us mental states of any kind…. I do not trouble myself about the mode of connection between mind and matter. …. That along with excitations or discharges of nervous arrangements in the cerebrum, mental states occur, I, of course, admit; but how this is I do not inquire; indeed, so far as clinical medicine is concerned, I do not care." (Hughlings Jackson 1931/1985, p.52)

Stay calm and carry on doing science!

Jackson's colleague, the physiologist David Ferrier goes a little further into the waters of metaphysics, by endorsing the view that the mental and physical are the "subjective" and "objective" sides of the one reality:

> "We may succeed in determining the exact nature of the molecular changes which occur in the brain cells when a sensation is experienced, but this will not bring us one whit nearer the explanation of the ultimate nature of that which constitutes the sensation. The one is objective and the other subjective, and neither can be expressed in terms of the other. We cannot say that they are identical, or even that the one passes into the other; but only, as Laycock expresses it, that the two are correlated, or, with Bain, that the physical changes and the psychical modifications are the objective and subjective sides of a 'double-faced unity'" (Ferrier 1876/1984, p.255-6)

[42] I provide no textual evidence that the authors quoted here were responding directly to du Bois-Reymond. Awareness of the mystery of mind-brain relationship was widespread enough that there need be no direct connection between these instances of discussion. See Chirimuuta (forthcoming).

This *dual-aspect* theory was in fact quite popular at the time amongst physiologists and psychologists, not only Thomas Laycock and Alexander Bain but also Gustav Fechner, Johannes Müller, and Herbert Spencer.

Huxley's ally in the campaign for naturalism, physicist John Tyndall, is a little more unusual in taking the awareness of the mystery to be a wellspring for the elevated feeling of wonder and awe whose presence in human experience seemed to be threatened by the retreat of religion (Barton 1987:133). Tyndall states the following in his Belfast Address of 1874, presented at the same meeting of the British Association for the Advancement of Science that Huxley gave his "conscious automata" lecture:

> "We can trace the development of a nervous system, and correlate with it the parallel phenomena of sensation and though. We see with undoubting certainty that they go hand-in-hand. But we try to soar in a vacuum the moment we seek to comprehend the connection between them. An Archimedean fulcrum is here required which the human mind cannot command; and the effort to solve the problem…. Is like a man trying to lift himself by his own waistband." Tyndall (1874:62)

For Tyndall, at least, the perception of the limits of science was inspiring, not demoralizing.

3. Conclusion

In my 2015 book I wrote that colours were not a problem before Galileo (Chirimuuta 2015:19). Here I've argued that "colours were not a problem before Helmholtz, Huxley and du Bois-Reymond." Or more accurately, I could say "new problems with colours came after du Bois-Reymond (and the others)" -- concerns that arose precisely because colours came to be located in a domain

of mental experience that defied mechanistic explanation.[43] For I should also point out that my alternative narrative is not strictly inconsistent with the more familiar one that places the action in the 17th century. Colours were *also* somewhat problematic for Boyle, Descartes and Newton, since each of these natural philosophers made statements which can lead one to wonder about the status of colour, as we perceive it, in a material world. And if we wished we could trace some of the puzzlement associated with sensory experience even further back to the atomists of the ancient world, as John Tyndall (1874) did.

So what argument is there for restricting ourselves to the close range historical view of just the era before our own? One reason is that in the concluding decades of the 19th century there was a new found emphasis on synthesising the advances of the sciences – across zoology, geology, physics, chemistry and physiology – into a coherent, naturalistic world view, one with a clear-cut separation between science and theology. It is when the ambitions of an all-pervading, naturalistic world picture come to the front of people's agendas that worries arise over what this new vision of the world leaves out. Du Bois-Reymond starts his lecture on the Limits of Science with the image of science as a military victor in the fashion of Alexander the Great:

> "JUST as a world-conqueror of ancient times, as he halts for a day in the midst of his victorious career, might long to see the boundaries of the vast territories he has subjugated more clearly defined, so that here he may levy tribute of some nation hitherto exempt, or that there he may discern some natural barrier that cannot be over-come by his horsemen, and which constitutes the true limit of his power, in like manner it will not be out of place, if Natural Science, the world-conqueror of our times, resting as on a

[43] As Zed Adams (personal communication) has pointed out, it is useful to think of their being multiple philosophical problems of colour, coming into existence at different historical points.

festive occasion from her labor, should strive to define the true boundaries of her immense domain." (du Bois-Reymond 1874:17)[44]

Subjective experiences – such as the simple pleasures of seeing and scenting a bunch of violets – are the refugees displaced with the all-conquering advance of modern science.

[44] "Wie es einen Welteroberer der alten Zeit an einem Rasttag inmitten seiner Siegeszüge verlangen konnte, die Grenzen seiner Herrschaft genauer festgestellt zu sehen, um hier ein noch zinsfreies Volk zum Tribut heranzuziehen, dort in der Wasserwüste ein seinen Reiterschaaren unüberwindliches Hinderniss, und somit eine wirkliche Schranke seiner Macht zu erkennen: so wird es für die Weltbesiegerin unserer Tage, die Naturwissenschaft, kein unangemessenes Beginnen sein, wenn sie bei festlicher Gelegenheit von der Arbeit ruhend die wahren Grenzen ihres Reiches enimal klar sich vorzuzeichen versucht." (du Bois-Reymond 1886:105)

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