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colour, philosophical issues. According to experience, tangerines are orange. According to science, tangerines are collections of colourless particles. There is some reason to think that the picture of the world provided by experience and the picture of the world provided by science are in conflict. This leads to perhaps the most central philosophical issue concerning colour, the issue of *realism* vs **eliminativism*. Realists hold that the pictures may be reconciled. Tangerines really are orange. By contrast, eliminativists hold that the two pictures cannot be reconciled. Tangerines appear orange, but are not really orange: the appearances are misleading. This view, then, eliminates colours from the physical world. This was the view taken by Galileo, who held that colours are only 'in the mind'. Notice that no analogous issue arises for other properties that we experience, e.g. shapes. There is no evident conflict between the picture of shape provided by experience and that provided by science.

There is a second philosophical issue concerning colour. Many philosophers wish to reductively explain all the properties of the common sense world in physical terms. This is due to the popularity of physicalism, the view that everything is explainable in physical terms (see *physicalism and *reductionism). Typically, the issue of reduction is discussed in connection with the mind, but the same issue arises in connection with colour. There are two views, *reductionism* and *primitivism*. Reductionists hold that colours can be reduced to physical properties. As we shall see, reductionism comes in two different versions. *Response-dependent reductionism* explains colours in terms of how objects affect perceivers. *Response-independent reductionism* explains colours in terms of physical properties of objects that are independent of perceivers, such as properties concerning how objects reflect light. By contrast to reductionists of either stripe, primitivists hold that colours cannot be reduced to physical properties. Primitivism is so called because it maintains that colours are basic or primitive properties that cannot be explained in other terms, much like fundamental physical properties such as *charge* and *mass*. So if one combines realism and primitivism, one takes the view that objects have colours *in addition* to their physical properties. This view, then, rejects reductive physicalism. It bears an obvious analogy to dualism because it recognizes a dualism of physical and chromatic properties at the surfaces of physical objects (see *dualism). Notice that no analogous issue arises for other properties that we experience, for instance shapes. Shapes are obviously physical properties. There is no *explanatory gap here. By contrast, many believe that, just as there is an explanatory gap between states of consciousness and physical properties, there is also an explanatory gap between colours and physical properties. So it is not obvious that colours are physical properties.

These two issues create a decision tree (see Fig. C4). If one accepts realism, one faces the choice between

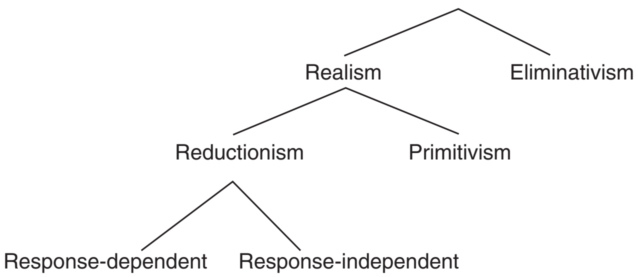

Fig. C4. Philosophical views on colour.

reductionism and primitivism. If one accepts reductionism, one faces the additional choice between response-dependent reductionism and response-independent reductionism. Alternatively, in view of the difficulties with realist theories, one might accept eliminativism, banishing colours from the external world. Let us now examine the four views at the end points in the decision tree, moving from left to right. We begin with views that combine realism and reductionism, which are popular among philosophers.

1. Response-dependent reductionism
2. Response-independent reductionism
3. Realist primitivism
4. Eliminativism

1. Response-dependent reductionism

Response-dependent reductionism (McGinn 1983) maintains that the property of being orange is a *secondary quality* of external objects: it is defined in terms of the responses objects produce in human beings. In particular, the property of being orange is the property of being disposed to produce orange experiences in normal individuals under normal conditions. By an 'orange experience', I mean the kind of experience one has when one looks at orange objects. To put it crudely, on this view, if a tangerine is in the forest and no species exists to see it, the tangerine is not orange. On response-dependent reductionism, then, colour is a perceiver-dependent property, like being funny or being poisonous. Yet it is a form of realism, because it holds that tangerines really are orange: they are orange, because they are disposed to produce orange experiences in normal individuals under normal circumstances. It is also a form of reductionism, because the property of being disposed to produce orange experiences in normal individuals under normal conditions is a physical property of objects if orange experiences in turn may be identified with physical (e.g. neural) states of persons.

One argument for response-dependent reductionism derives from the possibility of *biological variation* in colour vision (McGinn 1983). Consider a hypothetical case (Pautz 2006). Maxwell and Mabel belong to different species. Owing to naturally evolved differences between their colour systems, a tangerine normally appears orange to the members of Maxwell's species but pure red to the members of Mabel's species. Who gets it right? One option is to say that both get it right. A second option is to say that one gets it right and the other gets it wrong: for instance, the tangerine is orange but not pure red. A third option is eliminativism: neither gets it right. The second option appears arbitrary, and the third flies in the face of experience and common sense. Therefore one might think that the first option—chromatic liberalism—is the best. Response-dependent reductionism secures this result. On this view, when Maxwell says 'the tangerine is orange', he attributes to the tangerine the disposition to normally produce orange experiences in members of his species. When Mabel says 'the tangerine is pure red', she attributes to the tangerine the disposition to produce pure red experiences in members of her species.

But there are problems with response-dependent reductionism. First, it is not clear that it has a sound motivation. Each of the above three options has a cost. True, the claim that only one individual gets it right appears arbitrary, and the claim that neither gets it right is contrary to common sense. But many would say that the intuition goes against the verdict of response-dependent reductionism that both get it right. For Maxwell attributes the property of being orange to the tangerine and Mabel attributes the property of being pure red to the tangerine, and many have the intuition that a single object cannot be orange and pure red all over, contrary to response-dependent reductionism. So it is not obvious that this option is the best one. Indeed, in view of the problems with the various forms of realism, it may be that eliminativism is the best option. Second, many philosophers hold that response-dependent reductionism is phenomenologically implausible. Colours, they claim, do not look like dispositions to produce effects in us (Boghossian and Velleman 1989). Instead, they look like intrinsic, non-relational properties of objects on a par with shapes. Third, intuitively, to have an orange experience is to have an experience of the colour orange. The colour orange enters essentially into the specification of orange experiences. If so, then the response-dependent reductionist identifies the colour *orange* with the disposition to normally produce experiences of that very property, *orange*. This appears incoherent or circular (Boghossian and Velleman 1989).

2. Response-independent reductionism

By contrast to response-dependent reductionists, response-independent reductionists identify colours with response-independent properties of objects, that is, properties of objects that are completely independent of the responses objects produce in perceivers (Dretske 1995, Lycan 1996, Armstrong 1999, Tye 2000, Byrne and Hilbert 2003). On the most popular version of response-independent reductionism, colours are properties concerning the reflection of light, or *reflectance properties* for short. On this view, just as water is H_2O, the colour orange is a certain reflectance property. Like response-dependent reductionism, this view is both realist and reductionist. Colours are real properties of physical objects, and they are physical properties of physical objects.

On response-independent reductionism, by contrast to response-dependent reductionism, if a tangerine is in a forest and no species exists to see it, the tangerine is still orange, since the tangerine has the reflectance property that is identical with orange. Likewise, on response-independent reductionism, if we evolved a new colour vision system, so that tangerines came to look pure red rather than orange to us, then the tangerines themselves would remain orange, because they would retain the reflectance property that is identical with orange. By contrast, on a simple form of response-dependent reductionism, the correct description of this scenario is that tangerines change from orange to pure red (somewhat as a substance could go from being poisonous to being non-poisonous as a result of a change in our neurophysiology). In short, response-independent reductionism differs from response-dependent reductionism because it holds colour is an objective property like shape, rather than a perceiver-dependent property like being poisonous.

Typically, response-independent reductionists about colours accept a **representational theory* of our consciousness of colours. On this view, to be conscious of orange is simply to have an experience that represents or registers that something has the colour orange (which, on this view, is identical with a reflectance property). And, typically, they accept a *tracking theory* of sensory representation according to which the brain represents reflectance properties (on this view, colours) in the same way that a thermometer represents temperatures (see *intentionality). A pattern of neural firing represents or registers a certain reflectance property just in case it is caused by that reflectance property under optimal conditions (Tye 2000), or just in case it has the biological function of indicating that reflectance property (Dretske 1995). This philosophical view of colour fits well with the view in vision science that colour perception is a computational process whereby the reflectances and other properties of objects are recovered from the information arriving at the retina (Marr 1982).

What is the argument for response-independent reductionism? Like response-dependent reductionism, it is both realist and reductionist. So it agrees with experience and common sense, which have it that the world is coloured. And it agrees with physicalism, which seeks to explain everything in physical terms. At the same time, it avoids some of the difficulties with response-dependent reductionism. For instance, as noted above, many would say, against response-dependent reductionism, that colours do not look like dispositions to produce effects in us. Instead, they look like perceiver-independent of objects on a par with shapes. This is exactly what response-independent reductionism says colours are.

But there are also arguments against response-independent reductionism. First, what will the response-independent reductionist say about cases of biological variation, such as the case of Maxwell and Mabel? On a representational theory of colour experience, Maxwell represents the tangerine as *orange* and Mabel represents it as *pure red*. On response-independent reductionism, the represented properties *orange* and *pure red* are identical with different reflectance properties. Furthermore, response-independent reductionists hold that no surface can have *both* of these reflectance properties (Byrne and Tye 2006). Who then gets it right? One option for the response-independent reductionist is to say that the colour orange that Maxwell represents is identical with a reflectance property *R* that the tangerine does have, while the colour pure red that Mabel represents is identical with a different reflectance property *X* that the tangerine does not have (Byrne and Tye 2006). Call this *asymmetrical misrepresentation*. But there are two serious problems with this inegalitarian account of biological variation.

First, we may suppose that Maxwell and Mabel are alike at the receptoral level, so that their visual systems track exactly the same reflectance property *R* of the tangerine. They have different colour experiences because they naturally evolved different *postreceptoral* processing. So, when they view the tangerine and are put into different brain states, both of their visual systems are operating exactly as they were designed by evolution to operate. So, both brain states track *R* under optimal conditions, and both have the function of indicating *R*. So, given the stipulated basic physical facts of the situation, a tracking theory of representation predicts that both Maxwell and Mabel *accurately* represent the tangerine as having the reflectance property *R*. Thus, asymmetrical misrepresentation is incompatible with a tracking theory. In fact, no known theory of sensory representation supports this inegalitarian verdict. To underscore the problem, consider the following. According to asymmetrical misrepresentation, it is Maxwell who accurately represents the tangerine as having *R*, and it is Mabel who inaccurately represents it as having *X*. But if response-independent reductionism is correct, then another possibility is that it is Maxwell who inaccurately represents the tangerine as having *X*, and it is Mabel who accurately represents it as having *R*. (This option holds, contrary to the first option, that the orange colour that Maxwell represents is identical with *X*, and the pure red colour that Mabel represents is identical with *R*.) What could possibly make it the case that one of these possibilities obtains to the exclusion of the other? Apparently, the response-independent reductionist who favours asymmetrical misrepresentation must say that which of these possibilities actually obtains is a kind of primitive fact with no basis in the physical facts of the situation. In other words, he must give up on reduction. Yet achieving a reductive account was one of the motivations behind response-independent reductionism.

Second, the present account of biological variation may have the consequence that we cannot be said to know the colours of things. Maybe our own wiring, like Mabel's, makes us normally represent objects as having reflectance properties (colours) that they do not possess. Then our colour beliefs are false. If, on the other hand, our wiring, like Maxwell's, makes us normally represent objects as having reflectance properties that they do have, then this would seem to be a matter of luck. Either way, we cannot be said to know the colours of objects, which is contrary to common sense. So, given the account of biological variation under discussion, response-independent reductionism does not agree with the common-sense view of colour. Yet agreeing with common sense was one of its motivations.

A second argument against response-independent reductionism concerns *colour structure* (Hardin 1988). Blue resembles purple more than green does. Purple is a binary colour: every shade of purple is somewhat reddish and bluish. By contrast, green is a unitary colour. It does not contain a hint of any other colours. According to the opponent process theory of colour vision (see Hardin 1988 for an accessible account), we experience unitary and binary colours because of features of the colour vision system, although the neurobiological details remain poorly understood (see *colour, neurobiological approaches). But the belief that some colours are unitary while others are binary is justified on the basis of colour experience and experiments on colour naming. It does not stand or fall with any neurobiological theory of colour vision. Here now is the problem for response-independent reductionism. There is no obvious sense in which the blue-reflectance (the reflectance property the response-independent reductionist identifies with blue) resembles the purple-reflectance more than the green-reflectance. Nor is there any sense in which the purple-reflectance is binary, while the green reflectance is unitary (Byrne and Hilbert 2003). So, the colours our colour experiences represent have structural features which are not possessed by the reflectance properties which normally cause those colour experiences. But then colours must be distinct from those reflectance properties.

A third argument against response-independent reductionism is based on the intuition that there is an explanatory gap: however closely the colour orange and the reflectance property *R* may be correlated, they are intuitively wholly distinct from each other, just as pain is intuitively wholly distinct from the correlated brain state.

3. Realist primitivism

Some philosophers are attracted to the realist view that external objects are coloured, because it agrees with experience and common sense. But, for the reasons we have discussed, they are dissatisfied with both response-dependent reductionism and response-independent reductionism. These philosophers accept realism but reject reductionism, and accept primitivism instead (Campbell 1993, McGinn 1996). This combination of views is called *realist primitivism*. It is realist because it holds that the tangerine has the property of being orange. It is primitivist because it holds that the property of being orange is an extra, primitive property of the tangerine that cannot be identified with its disposition to produce orange experiences or its reflectance property *R*. To highlight this feature of the view, we might call this property *primitive orange*. On this view, then, colours are fundamental properties of the world, like *charge* and *spin*. As noted in the introduction, this view bears an obvious analogy to dualism because it recognizes a dualism of physical and chromatic properties at the surfaces of physical objects.

Now realist primitivists typically do not stop here. They typically say that the extra, primitive property of being orange 'supervenes on' or 'emerges from' some other properties of the tangerine (see *emergence). On one version of this idea, the property of being orange emerges from the tangerine's disposition to produce orange experiences in perceivers (McGinn 1996). So if a tangerine is in a forest and no species exists to see it, the tangerine does not have the emergent property of being orange, because it does not have such a disposition. This view is analogous to response-dependent reductionism. The difference is that it is a primitivist view, rather than a reductionist view: it holds that the property of being orange is an extra, emergent property of the tangerine, over and above its disposition to produce orange experiences in perceivers. Call it *response-dependent primitivism*. On another version, the property of being orange emerges from the tangerine's reflectance property *R*. So if a tangerine is in a forest and no species exists to see it, the tangerine nevertheless has the emergent property of being orange, because it has the reflectance property *R*. This view is analogous to response-independent reductionism. Again, the difference is that it is a primitivist view, rather than a reductionist view: it holds that the property of being orange is an extra, emergent property of the tangerine, over and above its reflectance property *R*. Call it *response-independent primitivism*. So, although this is not represented in Figure 1, primitivism as well as reductionism comes in response-dependent and response-independent versions.

What is the argument for realist primitivism of either variety? To begin with, it is a realist view, so it agrees with experience and common sense, which have it that external objects are coloured. At the same time, it avoids the problems with reductionism. For instance, it avoids Hardin's (1988) problem about colour structure. Even though reflectance properties are not unitary or binary, the colour properties that emerge from reflectance properties might be unitary or binary. And realist primitivism avoids the explanatory gap problem, because it endorses the intuition that colours are wholly distinct from reflectance properties.

But there are also problems with realist primitivism. First, one motivation behind realist primitivism is to accommodate common sense, but it is unclear that either response-dependent primitivism or response-independent primitivism accommodates common sense in its entirety. In fact, unsurprisingly, they share some of the problems of their reductive cousins, response-dependent reductionism and response-independent reductionism. Response-dependent primitivism (McGinn 1996) entails that, in the case of Maxwell and Mabel, the tangerine instantiates both primitive orange and primitive pure red, since it normally produces experiences of orange in members of Maxwell's species and it normally produces experiences of pure red in members of Mabel's species. This goes against the intuition that nothing can be both orange and pure red all over. And response-independent primitivism (Campbell 1993) may have the consequence that we cannot be said to know the colours of things. If this view is correct, then objects had response-independent primitive colours prior to the evolution of colour vision. Now, what colour vision system evolved (and hence what primitive colours objects look to have) in any given species was independent of the actual primitive colours of objects. Instead, it was determined by the peculiar set of selection pressures that operated on its ancestors: their habits, dietary needs, predators, and environments. It follows that if a species happens to evolve a colour vision system that makes objects look to have the primitive colours that they actually do possess, this can only be an accident. This seems to imply that no species (including *Homo sapiens*) can be said to know the primitive colours of objects. What is the point of claiming that objects have primitive colours if we cannot be said to know what those primitive colours are?

A problem that attends both versions of realist primitivism is that they are complicated, as they dualist views that hold that physical objects have 'extra' or 'emergent' colour properties over and above their physical properties. Therefore Occam's razor counts against both versions of realist primitivism.

4. Eliminativism

All forms of realism, then, face problems. These problems lend some support to eliminativism. On this view, a tangerine in the forest is not orange, even if someone is there to see it. On some versions, colours are 'only in the mind'. We evolved to experience objects as coloured, not because they really are coloured, but because experiencing objects as coloured enhances adaptive fitness. Philosophers today generally favour realism. But in the past many favoured eliminativism, including Galileo, Newton, Descartes, and Locke. And many contemporary vision scientists favour eliminativism. Thus, Zeki writes 'the nervous system '... *takes what information there is in the external environment, namely, the reflectance of difference surfaces for different wavelengths of light, and transforms that information to construct colours*, using its own algorithms to do so' (Zeki 1983:746, emphasis original).

I have noted that realist theories come in reductionist and primitivist versions. The same is true of eliminativist theories, although this is not represented in Figure 1. The eliminativist might hold that colours (or colour *qualia) reduce to neural properties of the brain, which we somehow mistakenly project onto external objects (Hardin 1988). Alternatively, he might hold that colours are primitive properties, which absolutely nothing has (Mackie 1976). On this view, colour properties only live in the contents of our experiences. Similarly, absolutely nothing has the property of being a winged horse: this property only lives in the contents of our thoughts.

The argument for eliminativism is that it provides the best overall account of the facts about colours. Consider, for instance, Maxwell and Mabel, who exhibit a case of biological variation. We have seen that response-independent reductionists accept asymmetrical misrepresentation: the verdict that one gets it right and the other gets it wrong. The problem is that they cannot provide an explanation of why one gets it right and the other gets it wrong, rather than the other way around. On eliminativism, both get it wrong, so there is no need to decide. And, crucially, the eliminativist may provide an explanation of why both get it wrong, which appeals (among other things) to the claim that objects do not have the colours presented to us in colour experience. The eliminativist can also account for facts involving the unitary–binary character of the colours. If he holds that colours are neural properties of the brain, he can treat them as neural facts. If he holds that colours are primitive properties that nothing has, he can treat them as primitive facts about colours. Finally, because eliminativism banishes colours from the external world, it is much simpler than realist versions of primitivism.

An obvious argument against eliminativism is that it flies in the face of experience and common sense, which have it that the world is coloured. In reply, the eliminativist might point out that the all of the realist theories we have examined depart considerably from common sense at some points. This illustrates a general feature of the philosophical debate concerning colour: here as elsewhere, there is no perfect theory. The best we can do is to try to draw up a balance sheet and see where the balance of considerations tilts.

A. PAUTZ

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colour vision, tetrachromatic. The term *tetrachromacy* describes the physiological possession of four different classes of simultaneously functioning retinal photopigments (also called *weak tetrachromacy*). From an empirical standpoint, tetrachromatic colour vision (or *strong tetrachromacy*) additionally requires demonstrating that mixtures of four independent appropriately chosen primary lights will simulate all distinctions in appearance possible in visible colour space. Independence of the primary lights implies that no mixtures of any subset of these lights (or their intensity variants) will produce an identical match to any combination of mixtures of the remaining lights. By comparison, *trichromacy* empirically requires only three primaries to simulate all visible colours.

Established theory states that humans with normal colour vision are trichromats (as, primarily, are Old World monkeys and apes). The first element of trichromacy is the output from three simultaneously functioning retinal cone classes: short-, medium-, and long-wavelength sensitive (SWS, MWS, LWS) cones. Three cone classes alone do not establish a trichromat colour code, however. A postreceptoral code for three categories of signal is also needed. A standard assumption in vision science is that the postreceptoral recoding of cone outputs initiates the neural trivariant (or trichromatic) property of human colour perception, and the need for only three primary lights to match any test light.

1. Animal tetrachromacy
2. Potential human tetrachromacy
3. Empirical studies of human tetrachromacy
4. Tetrachromacy controversies

1. Animal tetrachromacy

Tetrachromacy is an early vertebrate characteristic, existing in fish and reptiles, and is evolutionarily more ancient than primate trichromacy. Essentially all diurnal birds have four retinal cone types (two SWS classes, plus a MWS and a LWS class) which neurally produce four-dimensional colour experience, or tetrachromatic colour vision. Such birds probably perceive a greater number of distinct colours than humans do, and many more colours than dichromat mammals. Generally, non-human Old World primates tend to be trichromatic and New World primates dichromatic. Recent studies have found that some New World monkeys—the squirrel monkey, spider monkey, marmoset, and dusky titi—are colour vision polymorphic species in which the base condition is dichromacy, although a considerable proportion of individuals are trichromats (Jacobs 1996, Jacobs and Deegan 2005). Many animal species (e.g. squirrels, rabbits, some fishes, cats, and dogs) are dichromatic (as are some colour-deficient humans); they possess only two functioning classes of cone photopigments and need only two primary lights to match the colour of any test light.

2. Potential human tetrachromacy

Physiological considerations of potential human tetrachromacy began in the 1940s with genetic studies of inherited colour vision deficiencies or *Daltonism*. Approximately 8% of white males exhibit some degree of colour vision deficiency caused by inheriting altered LWS and MWS photopigment genes on the X chromosome. Males, possessing a single X chromosome, are less likely to express both LWS and MWS retinal photopigments than are females, who have two X chromosomes. Furthermore, a female carrying altered photopigment genes may not experience colour vision deficiency, although her male offspring will likely inherit it. Photopigment gene deletions during expression (due to intergenic non-homologous recombination), and alterations (due to missense mutations, coding sequence deletions, or intragenic crossover between different genes) underlie Daltonism. Failure to express either the LWS or