Mathematical Expressibility, Perceptual Relativity, and Secondary Qualities[1]

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Studies in History and Philosophy of Science 22, 1991, pp. 63-88.

During the seventeenth century, several apparently very disparate reasons were advanced for a believing that there is an important distinction between primary and secondary qualities. The most prominent were (1) the overall explanatory success of a physical science which refers only to primary qualities (2) the mathematical expressibility of primary but not secondary qualities, and (3) the immunity of primary but not secondary qualities to perceptual relativity arguments. The first of these would find sympathy today; questions about which types of qualities are real are often taken to be decided by the scientific theory that provides the best explanation for all of the relevant phenomena. But the second and third of these reasons may seem odd. Why should perceptual relativity or mathematical expressibility mark an important distinction among qualities?

I shall argue that mathematical expressibility and immunity from perceptual relativity indeed provide strong evidence for the reality of physical qualities. Furthermore, I shall contend that immunity from perceptual relativity and mathematical expressibility are intimately connected; what explains the plausibility of the perceptual relativity arguments also accounts for the power of the arguments from mathematical expressibility.

I

In order to explore these three reasons for distinguishing between primary and secondary qualities, we must first characterize the relevant version of the distinction. That version consists in a pair of theses, about which Galileo, Descartes, Boyle, and Locke, (and most contemporary participants in the discussion) agree. Let us briefly explore the views of these four philosophers.

Seventeenth century lists of primary qualities always include spatial extension and its modes, shape and size, temporal extension, or duration, and motion (Galileo, The Assayer, 274; Descartes, Pr. I, 68-9, AT VIIIA, 33-4; Locke, Essay, II, viii, 9; Boyle, OFQ 16). Some moderns add place and number (The Assayer, 274, Pr. I, 68-9, AT VIIIA, 33-4); Locke adds solidity (Essay II, iv; viii, 10). Later theorists add mass and various types of force. Locke and Boyle speak of texture (Essay II, viii, 10; OFQ, 23), which is a complex primary quality consisting in the shapes, sizes, and motions of an arrangement of corpuscles.[2]

By contrast, the lists of secondary qualities include color, odor, taste, sound, and tactile qualities like heat and cold. Our four philosophers differ on the ontological status of the secondary qualities. Galileo maintains that secondary qualities do not exist in the physical world:

> But that a [physical substance] must be white or red, bitter or sweet, noisy or silent, and of sweet or foul odor, my mind does not feel compelled to bring in as necessary accompaniments. Without the senses as our guides, reason or imagination would probably never arrive at qualities like these. Hence I think that tastes, odors, colors, and so on are mere names so far as the object in which we place them is concerned, and that they reside only in the consciousness. Hence if the living creature were removed, all these qualities would be wiped away and annihilated. (The Assayer, 274)

Descartes also flirts with this view:

> But for all the rest, including light and colors, I think of these only in a very confused and obscure way, to the extent that I do not even know whether they are true or false, that is, whether the ideas I have of them are ideas of real things or of non-things. (Med. 3, AT VII 43).[3]

Boyle maintains that bodies only dispositionally have colors and tastes, whereas they actually have only primary qualities

> if there were no sensitive beings those bodies that are now the objects of our senses would be but dispositively, if I may so speak, endowed with colours, tastes, and the like; and actually, but only with those more catholick affections of bodies, figure, motion, texture &c. (OFQ 25).

One might interpret Boyle to hold that colors are really in physical objects as dispositions to produce sensations in us, but the text does not sustain this view. He argues that secondary qualities are analogous to pain; pain is not really in the pin, although the pin is disposed to cause pain in certain sensitive creatures. Similarly, whiteness is not really in the snow, although the snow is disposed to cause sensations of whiteness in humans. (OFQ 24-5)

According to Berkeley, Locke also believes that secondary qualities do not exist, but Berkeley's interpretation is mistaken. Locke argues that secondary qualities are real things in the physical world; they are powers of physical objects to produce particular types of sensations in us in virtue of their primary qualities:

> Such Qualities, which in truth are nothing in the Objects themselves, but Powers to produce various Sensations in us by their primary Qualities, i.e. by the Bulk, Figure, Texture, and motion of their insensible parts, as Colours, Sounds, Tasts, etc. These I call

secondary Qualities. (Essay II, viii, 10, cf. 14, 22, 23)

Redness would, on this account, be the power an apple has to produce sensations in us in virtue of certain motions, shapes, sizes, and arrangements of corpuscles on the surface of the apple.

In the Principles, Descartes shies away from Galileo's view and endorses a position closely related to Locke's:

> the qualities in external objects to which we apply the terms light, colour, smell, taste, sound, heat and cold--as well as other tactile qualities and even what are called 'substantial forms'--are, so far as we can see, simply various dispositions in objects which make them able to set up various kinds of motions in our nerves <which are required to produce all the various sensations in our soul> (Pr. IV, 198, AT VIIIA 321-23, emphasis mine).

Here Descartes defines secondary qualities at least partly in terms of the primary qualities that cause them.

There are several versions of this type of view. One identifies secondary qualities with primary qualities, another rejects this identification in favor of specifying an essential connection between a secondary quality and a particular sensation. In the first, which I will call the reductionist position, secondary qualities are simply identified with primary quality complexes or textures. 'Red,' in referring to the quality of redness, would rigidly designate, say, a particular class of spectral-reflectance profiles C, or a class of molecular bases for such profiles, M. And even if it is possible that given a different psychophysical constitution, C or M would produce in us sensations similar to those we now have when we sense something yellow, C or M would still be redness. Our sensations of red merely fix the reference of 'red'; red itself consists solely in the primary quality texture cause of this sensation. 'Red' refers in the same way as Kripke believes

natural kind terms to refer; for 'water' as well as for 'red' our sensory experiences merely fix the referent of the term, and are not essentially tied to the referent.[4]

According to a second view, secondary qualities exist in the external world, but are essentially tied to particular sensations. Red is whatever physical quality causes a particular type of sensation, the type we (usually) think of as sensations of red. Suppose that a class of spectral reflectance profiles, C, causes the sensations we now typically associate with red. If at some future time C begins to produce sensations similar to those we now typically associate with yellow, and a different class of spectral reflectance profiles, D, produces the sensations we now typically associate with red, C would then constitute yellow and D red. Causing a sensation of a particular type is an essential feature of what red is, and not simply a reference-fixing device. One consequence of this position is that if there were no perceivers, no secondary qualities would exist. I believe that Locke holds this second position; let us call it the Lockean view.[5]

But whether or not Locke actually identifies secondary qualities with primary quality complexes, he certainly does not deny the existence of secondary qualities, as Galileo did. So what do our four modern philosophers agree on? There are two points of concurrence: first, there are no qualities in bodies that resemble the contents of secondary quality ideas, and second, all real qualities in the physical world either are primary qualities or are wholly constituted of (although not necessarily identical to) primary qualities.

So first, although Locke maintains that there are secondary qualities in the physical world, he denies the existence of secondary qualities of the sort that the medieval Aristotelians thought to exist. In order to grasp the Aristotelian notion, consider the Lockean distinction between a quality and an idea. An idea is a modification of the mind, whereas a quality is a feature of the external world which can be the causal basis of an idea. (Essay II, viii, 8) The

Aristotelian position is that both primary and secondary quality ideas resemble the qualities in the external world that (typically) cause these ideas. Just as the apple has a quality which resembles my idea of its shape, it also possesses a quality resembling my sensory idea of red. Let us call this quality 'Aristotelian red.' In general, an Aristotelian secondary quality will be a quality in the physical world which resembles the secondary quality idea it causes.

Galileo, Descartes, Boyle, and Locke, all deny the Aristotelian view that secondary quality ideas resemble their causes. Locke puts it this way:

> the Ideas of primary Qualities of Bodies are Resemblances of them, and their Patterns do really exist in the Bodies themselves; but the Ideas, produced in us by these Secondary Qualities, have no resemblance of them at all. There is nothing like our Ideas, existing in the Bodies themselves. They are in the Bodies, we denominate from them, only a Power to produce those Sensations in us: And what is Sweet, Blue, or Warm in Idea, is but the certain Bulk, Figure, and Motion of the insensible Parts in the Bodies themselves, which we call so. (Essay II, viii, 15; cf. The Assayer, 273-8; OFQ, 23; Med. 6, AT VII, 82)

Doubts might arise about the cogency of the notion of similarity between an idea and a physical quality.[6] Berkeley, for example, argues that ideas of qualities cannot resemble the qualities themselves because "an idea can be like nothing but an idea." (Principles 8, LJ II, 44) But Berkeley's view is difficult to reconcile with powerful intuitions we have about similarity. Compare an idea to a photograph. We have the intuition that in one clear sense a photograph of Einstein resembles Einstein himself, and this intuition cannot be undermined by the claim that a photograph can resemble only another photograph. We might invoke the notion of the pictorial content of a photograph, as opposed to its medium; the pictorial content of the photograph of Einstein resembles Einstein himself, even though the medium of the photograph resembles

nothing about Einstein. Analogously, it seems to make sense to say that the experiential content of my sensory idea of a shape resembles the shape in the external world, even though the medium of the idea resembles nothing about the shape in the external world. As J. L. Mackie states it, Locke maintains that shape, size, motion, rest, number and solidity, can belong to material things just as they occur as elements in my experiential content. Yet "we also commonly ascribe to material things colours as we see colours, as they occur as elements in our experiential content, and again heat, cold, roughness, and so on as we feel them... But this is all a mistake, a systematic error."[7]

This is not to say that according to Locke we never make errors in our primary quality perception. Yet even when we make mistakes, the objects have other determinate qualities belonging to the same determinable as those contained in our experiential content. When my idea represents something as being elliptical when it is in fact round, the object still has a quality similar to the experiential content of some shape perception. In the case of secondary quality perception, nothing in the external world is similar to the experiential content of any color idea.[8] Whether or not Locke's view is true, Berkeley's charge of unintelligibility is mistaken.

Thus the first thesis these four modern philosophers agree on is that there are no Aristotelian secondary qualities. The second thesis is that all real qualities in the physical world are either primary qualities or are wholly constituted of (although not necessarily identical to) primary qualities. This second thesis cannot be stated in terms of identity since Locke believes that what is physically real in secondary qualities is not identical to any particular primary quality or group of primary qualities, although it is wholly constituted of primary qualities. Galileo and Boyle would obviously agree to this second thesis. Whether Descartes' view on secondary qualities is like Galileo's, Boyle's, or Locke's, he clearly would endorse this position as

well.

In summary, although there are important disagreements among them on primary and secondary qualities, Galileo, Descartes, Boyle, and Locke agree that there are no Aristotelian secondary qualities, and that all real qualities in the physical world are either primary qualities or are wholly constituted of primary qualities. Furthermore, when the distinction between primary and secondary qualities is put this way, most contemporary participants in the discussion would also concur.

II

Let us now explore the three main reasons provided in the seventeenth century for these two theses about primary and secondary qualities.

(a) Best overall explanation.

Galileo, Descartes, Locke, and Boyle agree that the expected success of mechanistic science constitutes a reason for these two theses. According to early conceptions of mechanistic science, all features of the physical world can be explained in virtue of the motion and mechanical interaction of various parts of matter, where typical mechanical interactions are impact, pushing, and pulling. Mechanistic science allows us to explain all of the features of the physical world, including the physical aspect of the causal history of sensory ideas in us, in terms of the primary qualities alone. Secondary qualities are consequently not explanatorily primary, if they exist in the physical world at all. The core of this position is expressed by Descartes, who after providing much of his theory of the physical world in the Principles, concludes:

Up to now I have described this earth and indeed the whole visible universe as if it were a

> machine: I have considered only the various shapes and motions of its parts; (Pr. IV, 188, AT VIIIA, 315)

Descartes would agree that if all physical phenomena can be accounted for in terms of primary qualities, then there is no need to posit Aristotelian secondary qualities in the physical world.

According to the medieval Aristotelians, however, Aristotelian secondary qualities play an essential role in the explanation of secondary quality sensations. The modern philosophers were acutely aware of this, and attempted to provide an alternative theory of sensory awareness. Galileo, after explaining how all non-mental phenomena can be explained mechanistically, in virtue of primary qualities alone, tells us:

> To excite in us tastes, odors, and sounds I believe that nothing is required in external bodies except shapes, number, and slow or rapid movements. (The Assayer, 276)

In the Principles, Descartes, after providing an account of how sensation works, concludes that

> Now I have given an account of the various sizes, shapes, and motions which are to be found in all bodies; and apart from these the only things which we perceive by our senses as being located outside us are light colour, smell, taste, sound, and tactile qualities. And I have just demonstrated that these are nothing in the objects--or at least we cannot apprehend them as being anything else--but certain dispositions depending on size, shape, and motion. (Pr. IV, 199, AT VIII, 323)

Descartes and Galileo maintain that our secondary quality sensations do not require any causes in the physical world (outside of the person) besides primary qualities. The only external physical qualities these sensations depend on are size, shape, and motion.

Boyle also believes that Aristotelian secondary qualities are not needed to explain sensation:

> ...these sensories [i.e. sense organs] 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 the one light or colour, the other sound, the other odour, &c. (OFQ 23)

Again, the only physical qualities required to explain sensation are primary.

Locke's position is somewhat more complex. Margaret Wilson points out that he maintains that primary quality explanations of secondary quality ideas are incomplete.[9] Locke argues that there is no necessary connection between any particular primary quality texture and any particular sensation. Rather, sensory qualities ideas are linked up to particular primary quality textures by Divine agency (Essay, IV, iii, 13, 14, 28). But nonetheless, the only physical qualities required to explain sensation are primary.

According to many contemporary scientific realists, which physical qualities are real should be settled on the grounds of what theory provides a general best explanation for all physical phenomena. The modern philosophers maintain that the reality of primary qualities can be grounded in the explanatory power of mechanistic science. But they do not rely solely on an argument of this generality. They believe that focusing on certain special considerations will yield the same result. Exactly what are these special considerations and what evidence do they provide for our two theses about primary and secondary qualities?

(b) Perceptual relativity.

In II, viii of Locke's Essay we find the paradigm perceptual relativity argument:

> Ideas being thus distinguished and understood, we may be able to give Account, of how the same Water, at the same time, may produce the Idea of Cold by one Hand, and of Heat by the other: Whereas it is impossible, that the same Water, if those Ideas were really in it, should at the same time be both Hot and Cold. For if we imagine Warmth, as it is in our Hands, to be nothing but a certain sort and degree of Motion in the minute Particles of our Nerves, or animal Spirits, we may understand, how it is possible, that the same Water may at the same time produce the Sensation of Heat in one Hand, and Cold in the other... (Essay II, vii, 21)

The objective of this argument is twofold; first, to demonstrate that there is no Aristotelian temperature in physical objects, and second, to provide evidence for the mechanistic hypothesis. The argument is this: when one hand is antecedently warm, the other antecedently cold, the same water at the same time feels cold to one hand and warm to the other. But Aristotelian warm and cold would have to be mutually exclusive qualities; no one thing could be all Aristotelian warm and all Aristotelian cold at the same time. Thus the first conclusion is that the Aristotelian secondary qualities of warmth and cold do not exist in external objects; "it is impossible, that the same Water, if those Ideas were really in it, should at the same time be both Hot and Cold." The second conclusion is that the mechanistic hypothesis provides a better account of what is happening at the physical end of the sensory processes. The same primary quality in a thing can cause different sensations in the mind, depending on the initial state of the primary qualities in the different sense organs. Since the corpuscles in one hand are more agitated than those in the other, the effect on the two hands of the water, whose corpuscles are uniformly agitated, will be different. Hence, different sensations will be associated with each of the two hands.

To what must an idea be relative in order for it to fail to resemble a quality in the external

world? In Locke's water argument such an idea is relative to the state of the sensory apparatus of the perceiver. Such an idea might also be relative to the nature of the sensory apparatus of the perceiver, as in Berkeley's species-relativity considerations. Berkeley argues that if ideas in particular situations vary for different species, then we have good reason to believe that the idea does not resemble a quality in the external world.[10] Let us say, then, that in the broadly Lockean conception, an idea's varying with the state or nature of the sensory apparatus of the perceiver is evidence that this idea does not resemble the quality that causes it.

The perceptual relativity arguments reveal an important feature of the metaphysical project of the four philosophers we are discussing. In contrast with Berkeley, they maintain that there is a mind-independent physical world. In order to determine which physical qualities are real in this sense, one must separate the real from what are merely features of the human perspective in one's ideas. An obstacle is that we may represent features of the human perspective as genuine physical qualities. How do we distinguish the misleading from the veridical perceptions? Locke thought that if an idea of a quality varies with the state (or nature) of the relevant sensory organ, then we know that no quality similar to the experiential content of the idea is a feature of the objective physical world. One might suspect that he also thought that if a idea of a purported quality does not vary in this way, then we have evidence that it does resemble a real quality.

An analogy to non-biological detection mechanisms helps us see the value of the perceptual relativity arguments. Ian Hacking points out that it is a real possibility that some feature one sees through the lens of any microscope is an artifact of the microscope rather than a quality of the object on the slide.[11] If a feature is indeed an artifact of the microscope, one would expect it to be relative to the nature of particular types of microscopes, since microscopes vary

significantly in the way they work. A feature's being relative to the type of microscope would thus appear to be evidence that it is an artifact of the microscope itself. But if the feature can be seen through all types of microscopes, then it would seem to be a quality of the object on the slide.[12] Similarly, one can think of a perceptual mechanism as a detection device. If a quality shows up for all types of perceptual mechanism and for all states of any perceptual mechanism, then we would seem to have evidence that the quality is real. But if the quality only shows up for some types or states, then one might reasonably judge that the quality is a mere artifact of perceivers.

Some commentators, like E. M. Curley and Peter Alexander, assimilate perceptual relativity to perceptual error. This leads them to conclude that since primary and secondary quality perceptions are equally subject to error, the relativity arguments are fairly insignificant.[13] This assimilation is incorrect. Locke does not say that we make mistakes about temperature, but rather that our perceptions of temperature are relative to the states of our hands. The type of relativity Locke has in mind suggests that there is no plausible standard for considering one judgment about a purported quality correct and another not, whereas the possibility of error does suggest that there is such a standard. In the Lockean view, no justification exists for assuming that one hand rather than the other, or any other sensory measuring device in any state, embodies the right standard for judging Aristotelian secondary qualities.

A standard of this sort must exist for a quality if it is to be immune to arguments from perceptual relativity. When such a standard exists, different subjects can make reference to it in deciding the degree of a quality present. An objective standard thus allows for intersubjective agreement, and hence immunity from perceptual relativity arguments. Let us understand intersubjective agreement as the principled, non-arbitrary, agreement of a subject with herself,

with herself at different times, and with other subjects, including members of other species.[14]

(c) Mathematical expressibility.

Galileo and Descartes believe that our two theses, that there are no qualities in bodies that resemble the contents of secondary quality sensation, and that all real qualities in the physical world are either primary qualities or are wholly constituted of primary qualities, can be grounded solely in arguments from mathematical expressibility. Primary qualities, they maintain, lend themselves to geometrical characterization, whereas the Aristotelian secondary qualities do not, and hence we have reason to believe that the primary qualities, and not the Aristotelian secondary qualities, are features of the physical world. Initially, one might be skeptical about their view; if one has an empiricist bent of mind, one might suspect that Galileo's and Descartes's claim is simply an artifact of mystic Pythagoreanism. At the same time, belief in the evidential value of mathematical expressibility was essential to the success of the scientific revolution, and it is arguably a feature of the view of contemporary physical science. Thus it would be desirable to have an explanation for the evidential value of mathematical expressibility for deciding which physical qualities are real. Such an explanation would be successful if it demonstrated that mathematical expressibility has evidential value in virtue of evidential considerations that are more clearly acceptable and understandable.

One might be convinced of the evidential value of mathematical expressibility without an explanation of this type, and a comparison to simplicity is instructive here. Although many scientific realists hold that the simplicity of a theory has evidential value, it cannot obviously be explained in terms of evidential considerations that are more clearly acceptable and understandable. Perhaps all we can say is that simplicity has evidential value because it helps us

find powerful theories. By analogy, it might not be disastrous if we were in the same position with regard to mathematical expressibility. But nevertheless, as it would be preferable to have a satisfying explanation for the evidential value of simplicity, it would be better to have such an explanation for mathematical expressibility.

Let us attempt to characterize mathematical expressibility more precisely. In the Sixth Meditation, Descartes contrasts sensory with clear and distinct ideas, and states that all of the real qualities of bodies are clearly and distinctly understandable. For a physical quality to be clearly and distinctly understandable is for it to be mathematically expressible:

> ...corporeal things exist. They may not all exist in a way that exactly corresponds with my sensory grasp of them, for in many cases the grasp of the senses is obscure and confused. But at least they possess the qualities which I clearly and distinctly understand, that is, all those which, viewed in general terms, are comprised within the subject matter of pure mathematics. (Med. 6, AT VII, 80)

This passage yields a first indication about what it is for a quality to be mathematically expressible for Descartes: to be "comprised within the subject matter of pure mathematics." The Principles provide further elaboration:

> I am assuming that my readers know the basic elements of geometry already, or have sufficient mental aptitude to understand mathematical demonstrations. For I freely acknowledge that I recognize no matter in corporeal things apart from what the geometers call quantity, and take as the object of their demonstrations, i.e. that to which every kind of division, shape, and motion, is applicable. Moreover, my consideration of such matter involves absolutely nothing apart from these divisions, shapes and motions; and even with regard to these, I will admit as true only what has been deduced from

> indubitable common notions so evidently that it is fit to be considered as a mathematical demonstration. And since all natural phenomena can be explained in this way, as will become clear in what follows, I do not think that any other principles are either admissible or desirable in physics. (Pr. II, 64, AT VIIIA, 78-9)

According to Descartes, primary qualities are, in some sense, geometrical in nature. Extension is mathematically expressible in the sense that it is a geometrical quality. Extension, in Descartes' view, is the same thing as three-dimensional geometric space. Shape, size, and spatial position, as Descartes conceived them, are simply qualities of this space. Motion and duration, however, are not so obviously geometrical in this way, since, plausibly, there is more to motion and duration than their geometrical representation. In the above passage, Descartes indicates that motion is a quality "applicable" to extension. One reasonable hypothesis as to what he means is that one aspect of motion, trajectory, can be represented geometrically, as a curve through three-dimensional space. Another interpretation is that velocity, another aspect of motion, can be represented on a scale that has a spatial expression. This is just the way in which duration, as Descartes understood it, is mathematically expressible; duration can be represented on a scale in one-dimensional space, on a line. It seems reasonable to attribute to Descartes that, by contrast, Aristotelian secondary qualities are not mathematically expressible in any of these ways. For Descartes, then, Aristotelian color is neither a feature of geometric space, nor easily representable as a quality of this space, nor representable on a scale that has a spatial expression.

I shall argue that if mathematical expressibility has evidential value that can be explained, Descartes has left out certain important features of its characterization. Rudolf Carnap's account in his lectures on philosophy of science, which we shall now examine, includes these very features.[15] In addition, Carnap's characterization more accurately captures what physics has

come to recognize as mathematical expressibility. I believe that focussing on Carnap's picture will illuminate what is of scientific and philosophical value in the Cartesian conception.

According to Carnap, for a quality to be quantitative, it must be amenable to five rules. These rules are designed to capture the notion of a quality that can be represented on a scale:

(1) The first rule specifies that there must be an empirical test that specifies when two magnitudes of the quality are equal. For instance, one can specify that the lengths of two objects are equal if the ends match when they are put side by side.

(2) The second rule says that there must be an empirical test that tells us when one magnitude of the quality is greater than another. For example, the length of object A is greater than the length of object B if, when one end of A is matched up with one end of B, then the other end of A protrudes beyond the other end of B.

(3) The third rule defines an easily (and empirically) recognizable point of reference on the scale for the quality. We typically do this "by specifying an easily recognizable, and sometimes easily reproducible state and telling us to assign the selected numerical value [usually zero] to an object if it is in that state"[16] This rule might tell us to assign zero to length when it has no magnitude. In the case of temperature, we could assign zero to the freezing point of water.

(4) The fourth rule specifies a unit of measurement for the scale. This "rule of the unit..." "assigns a second selected value of the magnitude to an object by specifying another easily recognized, easily reproducible state of the object." The second value is usually 1, as in the case of the meter scale for length, although another value may be selected. In the case of the centigrade temperature scale, for example, we assign 100 to the boiling point of water.

(5) The fifth rule (which Carnap says is the most important) tells us under which empirical conditions two differences in the values of magnitudes for a quality are the same. For example, in the case of temperature, we might say that the difference between T(a) and T(b) is the same as the difference between T(c) and T(d) when the distance between the points at which a and b register on a mercury-filled tube is equal to the distance between the points at which c and d register.[17]

Carnap emphasizes that our choice of the empirical conditions for the fifth rule is of great importance. Suppose that, in the case of time measurement, we specify that two differences between temporal magnitudes are equal when they correspond to an equal difference in the number of my pulse-beats. Choosing such empirical conditions will lead to messy scientific laws. Instead, we might specify the empirical conditions in terms of the period of a pendulum, or the period of a cesium atom. Consider any two pendula of different lengths. Carnap points out that although their periods are not of the same duration, they are equivalent in the sense that the ratio of the duration of the period of one pendulum to that of the other is constant over time. There is an enormous class of periodic processes in nature that are equivalent in this sense to the periods of the two pendula, and moreover, there is only one such large class. By contrast, my pulse-beat is a member of only a very small class of equivalent periodic processes in nature.[18] Choosing one of the large equivalence-class of periodic processes will yield simpler and more elegant scientific laws.

Carnap would see the preferability of simple and elegant laws as a pragmatic issue. But the realist position, which I am assuming, would endorse a stronger interpretation of the data he adduces. The realist would claim that we have no empirical evidence that equal differences in numbers of my pulse beats consistently mark off real, mind-independent, equal differences

between temporal magnitudes. Yet, since there is an enormous class of periodic processes in nature that are equivalent to the periods of the two pendula, and since there is only one such large class, we do have good evidential support that the duration of the period of a pendulum really remains constant over time.

To summarize Carnap's scheme, a quality is mathematically expressible if it can be represented on a scale according to certain specifications. Empirical tests for equal and greater magnitude must be available, the scale must feature an empirically recognizable reference point, empirical definition of units of measurement must be possible, and there must be an empirical procedure that tells us when two differences in magnitudes of the quality are equal. Thus one might view Carnap's specifications as an elaboration of one aspect of the Cartesian notion of mathematical expressibility, representability on a spatial scale. I suspect that this aspect of the Cartesian notion is the one with the greatest philosophical significance.

Carnap's account is a sophisticated version of its Cartesian counterpart. One specification of great importance that Carnap contributes is that the scale be constructed so as to ensure that an empirical measurement procedure allows us to determine where any instance of the quality is on the scale. Since the empirical procedure is, in principle, available to everyone, this, in turn, allows for intersubjective agreement about the quality, and such intersubjective agreement provides evidence for this quality's reality. Galileo and Descartes do not draw our attention to these features of mathematical expressibility. They seem to believe that mathematical expressibility has evidential value for the reality of a quality all by itself, independent of an intersubjectively available measurement procedure. I shall argue that they are mistaken.

A skeptic might dismiss the evidential value of mathematical expressibility by pointing to the first type of reason we discussed, the power of mechanistic science to provide the best

explanation for all of the relevant phenomena. Descartes' mathematically expressible physical qualities also happen to be those referred to in mechanistic scientific theory. Accordingly, this skeptic might claim that although Descartes maintains that mathematical expressibility is the primary consideration for determining which physical qualities are real, he is simply relying on mechanistic science to do the work for him. I believe that to explain the success Descartes achieved one must admit that there is a grain of truth in this skeptic's position. Nevertheless, I shall argue that mathematical expressibility has real evidential value, and that it has a genuine explanation.

Carnap's rules isolate qualities for which a scale can be constructed in such a way as to allow for intersubjective agreement by means of an empirical measurement procedure. Hence, there is a potential link between the mathematical expressibility and the perceptual relativity arguments. Perhaps if a scale can be constructed for a quality according to Carnap's specifications, this scale can function as the standard which provides immunity to arguments from perceptual relativity.

III

Our discussion of the perceptual relativity arguments helps explain why they were of such great interest to Berkeley. In his view, there is no mind-independent physical world. Rather, the physical world is completely made up of sensory perspectives, by artifacts of perceivers. Berkeley argues that primary quality ideas are also relative to the perceptual mechanism, and that, therefore, they too are mere features of the sensory perspective. Hence, there is no distinction between primary and secondary qualities. Let us now consider the Berkeleyan objections to Locke's use of the relativity arguments to make a distinction between

primary and (Aristotelian) secondary qualities. Perhaps surprisingly, our analysis will illuminate an intrinsic connection between mathematical expressibility and perceptual relativity.

In the Dialogues, Berkeley attempts to undermine Locke's position by arguing that Lockean primary qualities are also relative to the state or nature of the perceptual mechanism. For instance, in the case of size, the mite sees his foot as big, whereas a human being sees it as small:

> Philonous: A mite therefore must be supposed to see his own foot, and things equal or even less than it, as bodies of some considerable dimension; though at the same time they appear to you scarce discernible, or at best so many visible points.
>
> Hylas: I cannot deny it.
>
> Philonous: And to creatures less than the mite they will appear as some huge mountain.
>
> Hylas: All this I grant.
>
> Philonous: Can one and the same thing be at the same time in itself of different dimensions?
>
> Hylas: That were absurd to imagine. (First Dialogue, LJ II, 188-9)

No quality in the foot could resemble the idea of big and the idea of small at the same time, so big and small are no different from the secondary qualities after all. Berkeley produces similar relativity arguments for many of the Lockean primary qualities.

On behalf of Locke, however, we can reply that Berkeley is correct in claiming that big and small cannot count as primary qualities. Indeed, their relativity to the perceptual mechanism counts as strong evidence that they lack mind-independent existence. Yet, Berkeley has not recognized two very significant points. First, there is a related quality that escapes the argument from perceptual relativity, and it is mathematically expressible. Big is not a primary quality, but

having a volume of 5 million cubic feet is. Similarly, fast simpliciter is not a primary quality, but moving at 120 miles per hour is. Second, the mathematically expressible qualities of volume in cubic feet and length in millimeters are immune to perceptual relativity arguments because all perceivers can come to agree about these qualities. We and the mite can agree that the mite's foot is .01 millimeters long, even though our judgment about whether it is big or small is relative to the state or nature of the perceptual mechanism.

Hence, according to this Lockean (and Cartesian!) reply to Berkeley, not all aspects of size, duration, and motion, as we perceive them, are primary qualities. Rather, in order to distinguish what is merely perspectival from what is real in our ideas of primary qualities, we can focus on the mathematically expressible features of the contents of these ideas. Finding the mathematically expressible feature is a way of isolating a quality on which we can all agree, one that is therefore immune to the perceptual relativity arguments.

Let us spell out this reply in more detail. Suppose we wish to determine whether size is a real physical quality. Initially, we must choose among several different possible notions of size. Some of these possibilities are: size relative to one's own sensory perception after thinking about galaxies, size relative to one's own sensory perception after thinking about microphysics, and size relative to the sensory perceptions of various other types of conscious beings. None of these are plausibly notions of a real, perspective-independent quality. But suppose we turn to mathematical expressibility, in particular to Carnap's formulation of this notion, to determine a notion of size for us. These rules isolate a quality from among these possibilities that is not relative to the perceptual mechanism, and thus plausibly real. They do so by distinguishing a quality that is mathematically expressible in the sense that it can be represented on a scale constructed according to certain specifications, which assure that this quality can be measured in

accordance with the scale. This type of mathematical expressibility allows for intersubjective agreement, and thus excludes perceptual relativity, because the scale, the measurement procedure, and the measurement results, are in principle accessible to all subjects. The scale and the measurement procedure provide a standard to which all subjects can make reference. Consequently, if a purported physical quality is mathematically expressible in this sense, it will not be relative to perceptual mechanisms, but amenable to intersubjective agreement, and we will thus have evidence for its reality.

Our Lockean reply is directed towards Berkeley's application of the relativity arguments to the primary qualities. But, one might object, can we not provide similar replies for Locke's own application of such arguments to the secondary qualities? Although warm and cool are relative to the perceptual mechanism, the mathematically expressible aspect of temperature, which we measure with a thermometer, is not. So there is no disanalogy between size and temperature. Just as for size, some, but not all, aspects of temperature are relative to perception. Perhaps an aspect of color, like a class of spectral reflectance profiles, is also mathematically expressible and not relative to perception. Hence the relativity arguments and mathematical expressibility do not seem to yield a primary/secondary quality distinction after all.

But this objection can be answered. These two considerations do not distinguish between primary qualities and the secondary qualities of the Lockean or the reductionist, but between primary qualities and Aristotelian secondary qualities, where an Aristotelian secondary quality is a quality in the physical world that resembles the secondary quality sensation of it. Mathematically expressible temperature and sound are not Aristotelian secondary qualities. Rather, they are the secondary qualities of the Lockean or the reductionist, and Locke and the reductionist argue that such qualities exist in the physical world.

Thus, here is the view that emerges from our discussion. For Galileo and Descartes, the ideal of mathematical expressibility plays a pivotal role in the development of their conception of the physical world and motivates their attachment to mechanistic science. Initially, their belief in the evidential value of mathematical expressibility seems to be without explanation, but a consideration of the relativity arguments provides an opposing perspective. These relativity arguments serve to distinguish real from unreal qualities because they assist us in separating mere elements of the human perspective from representations of real physical qualities. In certain cases, however, in order to escape the relativity arguments and come to intersubjective agreement, we must isolate a mathematically expressible quality from among a range of possibilities. Hence, to achieve intersubjective agreement, we can focus on temperature in degrees Kelvin rather than on felt temperature, and on velocity in kilometers per hour rather than on velocity as sensed. Carnap's rules spell out the notion of mathematical expressibility that allows us to isolate such qualities. Consequently, in spite of its Pythagorean motivation, the evidential value Descartes and Galileo attributed to mathematical expressibility can be vindicated.

IV

Let us assess our progress so far. We have considered these three claims: the relativity arguments allow us to discriminate between real qualities and those that are mere artifacts of the perceptual mechanism; mathematical expressibility considerations allow us to make such discriminations; and there is an intrinsic connection between the relativity arguments and mathematical expressibility. To become precise about the status of these claims, we must focus more carefully on each of them.

The following two theses about the relativity arguments can be distinguished:

(a) An idea of a purported physical quality being relative to the state or nature of the perceptual mechanism constitutes strong evidence that the quality (as represented) is not real (i.e. is not a real physical quality).

(b) An idea of a purported physical quality not being relative to the state or nature of the perceptual mechanism constitutes strong evidence that the quality (as represented) is real.

Let us, in turn, consider objections to both of these theses. I shall argue that (a) is clearly true, while (b) is more difficult to assess.

Against (a) one might claim that even when an idea of a physical quality is relative to the state or nature of the perceptual mechanism, we cannot conclude that the quality, as we represent it, is not real. For it is possible that given only the result of the perceptual relativity experiment, the temperature of Locke's water resembles the idea perceived by means of the warm hand while the idea perceived via the cool hand does not resemble the real quality. In the case of color, even though ideas may change as the state and nature of the sensory processes vary, perhaps the color ideas normal human perceivers have on a clear day at noon are the ones that resemble the real qualities.

Margaret Wilson discusses this type of reply, provided by I. C. Tipton and George Pitcher, to the two sorts of perceptual relativity arguments discussed by Berkeley, arguments from species relativity (relativity to the nature of the perceptual mechanism) and arguments from relativity to the state of the perceptual mechanism.[19] According to the species relativity argument, the experiential content of a human idea does not resemble a real quality because members of other species (bees, for example) have ideas with different experiential contents in the same perceptual situations, while having discriminatory power comparable to humans. Focussing on color, she agrees to the reply that species relativity "is not logically inconsistent

with the view that the colors humans see are real qualities in things," although "it does manage to make this position look rather ill-founded."[20] If the vision of another species were like color-blindness, it would be natural to consider it a perceptual defect. But since it is not like color-blindness "it is much less natural to hold that the bee's vision is abnormal or defective relative to my own."

Wilson, I believe, is right in her response, although it can be spelled out in more detail to reveal several significant features of the perceptual relativity arguments. It is natural to think that color-blind people have defective vision because (1) they lack the ability to make discriminations that others can make, and (2) the legitimacy of these discriminations can be theoretically confirmed. Persons with normal vision can discriminate between red and green, whereas certain color-blind persons cannot. We need (2) in order to rule out bogus discriminations. Normal discrimination can be legitimated by showing that there are wavelength properties that normal perceivers can discriminate from others distinct from them, whereas color-blind perceivers lack this ability. If the vision of another species does not meet these conditions, it is reasonable to consider it defective.

But suppose the vision of another species is not defective, and their color qualia do not match ours. Then it cannot be the case that both our qualia and theirs can resemble the physical qualities. But then, the thesis that the qualia of either species matches the physical qualities is ad hoc and does no explanatory work. This argument is neither deductive nor a priori; rather it is a scientific argument that rules out the Aristotelian hypothesis because it is not the best explanation of the phenomena. Given species relativity, Pitcher is right in pointing out that it is nevertheless logically possible that there are Aristotelian colors. Yet since the claim that Aristotelian colors exist is not a feature of the best scientific theory, Pitcher's point does not

undermine the species relativity arguments.

> Secondly, Wilson thinks that
>
> the species relativity hypothesis provides at least prima facie reason to question the apparent grounds for our normal assumption of the mind-independent status of colors. That things' colors have an out-thereness, a constancy, a predictability, a fixedness, an intersubjective verifiability--all features we associate with independence of ourselves seems to be what convinces us that colors are qualities picked up by our perceptual systems, rather than projections of them.

Species relativity suggests that "the colors of the world could have all these "objective" features, and yet be to a perceiver systematically different, without any changes in the colored things." Wilson is right, again because the Aristotelian thesis is not part of the best explanation for species-relativity. It is logically possible that our perceptual systems pick up on (Aristotelian) color, i.e. that the experiential content of our color perceptions resembles qualities of the external world, but the better explanation does not have this thesis as a consequence.

To the arguments from relativity to the state of the perceptual mechanism, George Pitcher replies that they at most show that we can never know what the true color of something is, while they cannot establish that colors are mind-dependent (i.e. they cannot establish that what appear to be the colors of things are merely features of contents of perceptions).[21] Wilson replies that these arguments nevertheless put the proponent of the mind-independence of color (i.e. the view that Aristotelian colors exist) in an awkward position. For it would be bizarre for the anti-Berkeleyan to take the position that some colors as perceived are or may be mind-independent qualities, but we cannot know which ones fit this description. Again, Wilson's remark can be cashed out in terms of best explanation. If the arguments from relativity to the state of the

perceptual mechanism were supposed to be deductive, then Pitcher's reply is on target. But since they are scientific arguments to the best explanation, his reply is not to the point. Thus the types of objections that Pitcher raises against the perceptual relativity arguments can be answered, and a purported quality's relativity to the perceptual mechanism is indeed strong evidence of unreality.

Arguments from perceptual relativity are thus arguments to the best explanation. Plausibly, arguments from mathematical expressibility have the same status. But what is the relation of these two special considerations to the argument to the best overall explanation for which qualities are real? My answer is fairly simple. Intuitively, this general argument has many components, in the sense that it musters many different bits of evidence to support its conclusion. Arguments from perceptual relativity and mathematical expressibility exhibit particularly important evidence for this conclusion. Thus, I believe we should regard these arguments as especially significant components of an argument to the best overall explanation for deciding which qualities are real.

V

Is a quality's not being relative to the state or nature of the perceptual mechanism strong evidence of its real existence? Against

(b) An idea of a purported physical quality not being relative to the state or nature of the perceptual mechanism constitutes strong evidence that the quality (as represented) is real

one might object that immunity to relativity arguments can be achieved for colors and temperatures as sensed, which we know to be unreal. For instance, we can achieve intersubjective agreement across human beings for temperature as sensed by creating a scale in

terms of expert discriminators, standardized conditions, and just-noticeable differences. Disagreements due to different initial temperatures of the sense organs can be adjudicated with reference to standardized conditions. Disagreements about where some sensed temperature is on the scale can be settled by deferring to the expert discriminators. These experts can also be used to set the standard for just-noticeable differences. Objective ratios of different parts of the scale can be determined by differences the expert discriminators can distinguish.[22] So intersubjective agreement can be achieved about the degree of a purported quality present without the quality being real. I believe that this shows (b) to be false.[23]

But nonetheless, even though immunity of an idea to the relativity arguments is not strong evidence that there is a quality in the physical world similar to the experiential content of idea, it would seem to be evidence either that there is such a quality or that there is a physical quality appropriately causally correlated with the experiential content of the idea. For instance, the kind of intersubjective agreement we can reach on felt temperature seems to suggest that there is some mathematically expressible physical quality, like mean molecular kinetic energy, whose degrees causally correlate with the degrees of our felt temperature scale. The causal correlation would have to meet certain conditions, for example, that an appropriate mathematical relation exist between the scale for the one type of quality and the scale for the other. Let us thus consider the following liberalized version of (b):

> (b') An idea of a physical quality not being relative to the state or nature of the perceptual mechanism constitutes strong evidence that either the quality (as represented) is real or there is a type of real physical quality whose various degrees are appropriately causally correlated with the degrees of the experiential contents of the idea.

Against this one might argue that immunity to the relativity arguments does not guarantee even

that there is a causal correlation of the sort described. Intersubjective agreement might be explained by similarity of neurophysiological structure, which may produce similar artifacts of the perceptual mechanism across individuals, while the qualities in the physical world that generate these similar artifacts are of many disparate types. For instance, if C. L. Hardin is right in Color for Philosophers, no single type of physical quality is correlated with a single type of color idea, and the explanation as to why many different physical qualities produce the same type of idea depends heavily on the nature of the neural mechanisms that process information about these qualities. Sensations of unique yellow (yellow without any apparent admixture of orange or green) can be produced by light of wavelength 580 nanometers, or a combination of light of 540 and 670 nanometers, and an indefinite number of other combinations.[24] The only reason we have to class all of these wavelengths into a single group is that they all cause the same type of sensory idea, and the reason they do depends essentially on the nature of our neurophysiology. Hardin argues that from the point of view of physics, no physical qualities that underlie yellow sensations form a natural kind.[25]

But if intersubjective agreement could be achieved across species, we would have much stronger evidence for the real existence of either the quality as perceived or a physical quality that is appropriately causally correlated. One might object that it is possible that in virtue of evolutionary history, the color sensors of all (the relevant) species might have the same structure. If this were so, inter-species agreement about color would be possible, even if there were no physical quality appropriately causally correlated with our color sensations. But this is a mere possibility, and it does not show that immunity to all of the relativity arguments fails to provide fairly strong evidence for either for the reality of either the quality as perceived or of some quality that is appropriately causally correlated with the experiential contents in question. Thus,

I would venture that (b') is indeed true.

VI

It is tempting to endorse counterparts of (a) and (b') for mathematical expressibility:

(c) A purported physical quality not being mathematically expressible, as defined by Carnap's five rules, constitutes strong evidence that the quality (as represented) is not real.

(d') A purported physical quality being mathematically expressible, as defined by Carnap's five rules, constitutes strong evidence that either the quality (as represented) is real or there is a type of real quality whose various degrees are appropriately causally correlated with the degrees of experiential contents of the idea of the quality.

I see no special reason to reject (d'). The same considerations that indicate that (b') is true, provide evidence for (d'). And the same considerations that motivate the formulation of (b') in terms of strong rather than conclusive evidence do so for (d').

However, (d') allows for (1) purported qualities that are mathematically expressible and real, and (2) those that are mathematically expressible and not real, although real qualities are correlated with the experiential contents of the idea of the quality. But then, if Descartes and Galileo depend solely on mathematical expressibility to make their distinctions between the real and the unreal physical qualities, how could they know that shape, size, and motion are real and not merely contents of ideas to be correlated with real qualities? I believe that here one is forced to admit that they are relying on an argument from the overall explanatory success of mechanistic science for their position, and that mathematically expressibility by itself could not yield their conclusions. In making their distinctions, they depend, to some extent, on the

mechanistic view of the physical world.

But what about (c)? Upon reflection, it seems false. Being a neutron and being a quark are real physical qualities, but are they mathematically expressible? Perhaps these qualities quite trivially fit Carnap's five rules. One can tell when two things are both fully neutrons, when one thing is a neutron and another is not, one can devise a scale with 0 standing for 'is not a neutron' and 1 for 'is a neutron,' and one need not worry about whether the ratios of parts of the scale to one another because the scale only has one part. But the way in which being a neutron fits Carnap's rules is trivial, and one can perform the same trick on many intuitively real as well as non-real all-or-nothing qualities.

Here it is best to retreat. Actually, the kind of mathematical expressibility we have been considering applies only to those physical qualities that intuitively come in degrees; Carnap's rules, for instance, only makes sense for such qualities. Let us relativize our condition to such qualities:

> (c') A purported physical quality not being mathematically expressible, as defined by Carnap's five rules, given that it intuitively comes in degrees, constitutes strong evidence that it is not real.

This condition, I believe, is true.

We can now state more exactly the conditions under which the mathematical expressibility of a quality makes it immune to perceptual relativity arguments. For purported physical qualities that intuitively come in degrees, distinguishing a quality about which we can all agree amounts to discovering a quality which is immune to perceptual relativity arguments. Carnap's scheme is the method we use to isolate such qualities from a range of possibilities. Thus, plausibly,

(e) given that a physical quality intuitively comes in degrees, ideas of it are immune to perceptual relativity arguments just in case the quality is also mathematically expressible.

Perhaps there is some way, other than by a process of the sort Carnap describes, to distinguish a physical quality that intuitively comes in degrees and is immune to perceptual relativity arguments. If there really is such a way, (e) will not be exceptionless. But I am not aware of such a method.

These reflections allow us to become more precise about the role mathematical expressibility plays in the project of discovering which purported qualities are real. For physical qualities that intuitively come in degrees, we must seek a framework that allows us to come to agreement on the degree of the quality present, and second, a quality that fits this framework. The framework we need is made up of a scale and a method for determining the position on the scale for any instance of the quality. A quality is mathematically expressible in virtue of the representability of its various degrees on a scale that meets Carnap's specifications. Such mathematical expressibility allows us to isolate a quality to which we can apply an empirical measurement procedure that meets certain standards, and hence, ensures the possibility of intersubjective agreement and immunity to perceptual relativity arguments.

It is crucial that the quality be mathematically expressible in the sense that its various degrees can be represented on a scale which allows for an intersubjectively accessible empirical measurement procedure. Without this feature, mathematical expressibility does not provide evidence for the reality of a purported quality. If Carnap's rules permitted each individual to devise his own private scale, and produce his own private readings, then amenability to these rules would not be evidence for the reality of a quality. Such mathematical expressibility would provide no evidence that the qualities represented on the scale were not artifacts of perceptual

mechanisms. But if the scale allows for determinations that are accessible to anyone, then we have evidence that they are detections of features of the external world.

Cartesian geometrical expressibility plausibly guarantees the existence of a scale for the quality being expressed, but it fails to ensure that different individuals be able to agree about the position on the scale of particular instances of the quality. Carnap's rules ensure this feature by specifying that the scale allow for an intersubjectively accessible measurement procedure. Perhaps Descartes was able to ignore this crucial feature of mathematical expressibility because the requisite measurement procedures for his primary qualities, like shape and size, are easily taken for granted. But although Descartes did not acknowledge the link between mathematical expressibility and an intersubjectively accessible measurement procedure, without it the success of his geometrical method remains unexplained.

Acknowledgements -- I wish to thank Robert Adams, Lynne Rudder Baker, David Christensen, Richard Healey, Jeremy Hyman, Hilary Kornblith, Arthur Kuflik, George Sher, and a referee for Studies in History and Philosophy of Science for enlightening discussion of various issues in this paper.

NOTES

1. Abbreviations for works cited in the text of this paper are:

LJ: George Berkeley, The Works of George Berkeley, Bishop of Cloyne, ed. A. A. Luce and T. E. Jessop, 9 vols., (Edinburgh: Thomas Nelson, 1948-57). (Principles: Principles of Human Knowledge)

OFQ: Robert Boyle, Origin of Forms and Qualities, from The Works of the Honorable Robert Boyle, vol. 3, (Hildesheim: Georg Olms, 1966).

AT: René Descartes, Oeuvres de Descartes, edited by Ch. Adam and P. Tannery (revised edition, Paris: Vrin/C.N.R.S., 1964-76). Quotations are from The Philosophical Writings of Descartes tr. John Cottingham, Robert Stoothof, and Dugald Murdoch, 2 vols., (Cambridge: Cambridge University Press, 1985). (Med.: Meditations on First Philosophy; Pr.: Principles of Philosophy)

The Assayer: Galileo Galilei, The Assayer, in Discoveries and Opinions of Galileo, tr. Stillman Drake, (New York: Doubleday Anchor, 1957).

Essay: John Locke, Essay Concerning Human Understanding: ed. Peter Nidditch, (Oxford: Oxford University Press, 1975).

2. Sometimes Locke lists the primary qualities in their determinable, rather than their determinate form, for example, instead of motion listing mobility, or instead of shape flexibility. For an account of the various lists of primary qualities in Locke and Boyle, and for a discussion of the determinable/determinate distinction, see Peter Alexander, Ideas, Qualities, and Corpuscles: Locke and Boyle on the External World, (Cambridge: Cambridge University Press, 1985), pp. 78-9, 133ff.

3. Galileo's position has been defended recently by Paul Boghossian and David Velleman in "Colour as a Secondary Quality", Mind, vol. xcviii, no. 389, January 1989, pp. 81-103. The authors argue that the physicalist account and various dispositionalist accounts of color are false. In all of their arguments,

however, they utilize the thesis that the correct analysis of color is an analysis of color experience, or more precisely, how color appears or what we see color as. They rule out the view that color is a class of spectral reflectance profiles by saying that we do not experience color as spectral reflectance profiles, and that color is not a disposition because we do not see it as a disposition. But they fail adequately to rule out the view that color is the property in the world that causes our color experience, whether or not color appears to us as one of these causes. Their only attempt to argue against this thesis occurs at the beginning of the article, where they say that since physics determines what properties are real, and color is not among them, the analysis of color should not concern the underlying cause. But this is a faulty argument, since (1) for all they have said, color might be reducible to these physical qualities, and (2) there are many qualities in the world, like being a gene, over which physics does not quantify, are not reducible to physics, and are yet not qualities that fall out of an analysis of experience. A more convincing defense of Galileo's view can be extrapolated from C. L. Hardin, Color for Philosophers, (Indianapolis: Hackett Publishing Company, 1988), pp. 59-67. This account is presented in outline in section V.

4 Saul Kripke, Naming and Necessity, (Cambridge, Mass: Harvard University Press, 1980).

5. Colin McGinn, in The Subjective View, (Oxford: Oxford University Press, 1983) argues that Locke holds this second position. Peter Alexander disagrees. He argues that in Locke's view, secondary qualities are reducible to textures, and that in all the passages where Locke suggests that colors and sounds would no longer exist if minds disappeared, words like 'colour' and 'sound' refer to ideas and not to secondary qualities. (Alexander, pp. 138, 169). I think that the following passage is difficult to reconcile with this interpretation:

> For though Fire were called painful to the Touch, whereby is signified the power of producing in us the Idea of Pain; yet it is also denominated Light and Hot; as if Light and Heat, were really something in the Fire, more than a power to excite these Ideas in us; and are therefore called

> Qualities in, or of the Fire. But these being nothing, in truth, but powers to excite such Ideas in us, I must, in that sense, be understood when I speak of secondary Qualities, as being in Things; or of their Ideas, as being in the Objects, that excite them in us. Such ways of speaking, though accommodated to the vulgar Notions, without which, one cannot be well understood; yet truly signify nothing, but those Powers which are in Things, to excite certain Sensations, or Ideas in us. Since there were no fit Organs to receive the impressions Fire makes on Sight and Touch; nor a Mind joined to those Organs to receive the Ideas of Light and Heat, by those impressions from the Fire, or the Sun, there would yet be no more Light, or Heat in the World, than there would be Pain if there were no sensible Creature to feel it, though the Sun should continue just as it is now, and Mount Aetna flame higher than it ever did. (Essay, II, xxxi, 2, emphasis mine)

6. See E. M. Curley, "Locke, Boyle, and the Distinction between Primary and Secondary Qualities", Philosophical Review 81, 1972, pp. 451-4.

7. J. L. Mackie, Problems From Locke, (Oxford: Clarendon Press, 1976), pp. 10-11.

8. Mackie, pp. 10-11.

9. Margaret Wilson, "Superadded Properties: The Limits of Mechanism in Locke," American Philosophical Quarterly, V. 16, n. 2, April 1979, pp. 143-150.

00. George Berkeley, Three Dialogues Between Hylas and Philonous, First Dialogue, LJ II, 171ff.

11. Ian Hacking, Representing and Intervening, (Cambridge: Cambridge University Press, 1983), pp. 186-209.

22. Hacking, p. 204.

33. Assuming that relativity to perception is the same as perceptual error, Curley (op. cit.) points out that Locke was aware of the possibility of misperceptions of primary qualities, that Malebranche provides a long discussion of the issue in Recherche de la verité (a book Locke read and commented on) and that Locke uses examples of misperceptions of shape (Essay II, 9, 8), and motion (Essay II, 14, 6). With this in mind, he argues that in the water passage Locke is "not... concerned to argue that, because we may err about temperatures, things do not really have temperatures or that, because our perceptions of temperature vary with the conditions under which temperatures are perceived, temperatures are not genuine qualities of objects." Rather, what Locke is concerned about is "providing indirect evidence for a particular mechanical theory about the causation of our perceptions of heat--namely, the theory that our perceptions of heat and cold are caused in the first instance by variations in the motion of the particles making up our nerves." The mechanical theory explains how the motion of particles in the hands can influence sensation together with the motions of particles in the water. Thus, in Curley's view, the water experiment is supposed to demonstrate not the unreality of any kind of secondary qualities, but only the power of the mechanistic hypothesis.

A reason to reject this interpretation is that Locke clearly indicates that the relativity argument distinguishes primary from secondary qualities:

> we may understand, how it is possible, that the same Water may at the same time produce the Sensation of Heat in one Hand, and Cold in the other, which yet Figure never does, that never producing the Idea of square by one Hand, which has produced the idea of Globe by another. (Essay II, viii, 21)

Curley thinks that Locke isn't making a general statement about primary qualities here, only about one particular primary quality. But this is implausible, since the general topic of the section is to differentiate between primary and secondary qualities. At the very least, if Curley is right, Locke's contrast of shape, a primary quality, with (Aristotelian) temperature, is very misleading.

Alexander provides an interpretation similar to Curley's (Alexander, p. 128). Both Alexander and Mackie (Mackie, p. 22-3) attempt to denigrate Locke's contrast to perceptions of primary qualities by pointing out that he also mentions illusions in our perceptions of shape. These commentators agree that if only Locke were more circumspect, he would indicate that shape-illusions could also be explained by the mechanistic hypothesis. This interpretation attributes a rather dramatic oversight to Locke. Moreover, as I explain here, the notions of illusion and error presuppose a standard for judgment, whereas Locke's relativity arguments presuppose that there are no standards by means of which to attribute error to judgments about Aristotelian secondary qualities.

44 Sometimes intersubjective agreement about the existence of a quality is achieved not because different subjects actually have similar sensations, but by means of less immediate and more theoretical considerations.

55. Rudolf Carnap, An Introduction to the Philosophy of Science, ed. Martin Gardner, (New York: Basic Books, 1966), pp. 62-69.

66. Carnap, p. 64.

77. Carnap, p. 65.

88 Carnap, p. 83.

99. I. C. Tipton, Berkeley: The Philosophy of Immaterialism, (London: Methuen, 1974), pp. 251-5; George Pitcher, Berkeley, (London: Routledge and Kegan Paul, 1977), pp. 104-6.

00. Margaret Wilson, "Berkeley on the Mind-Dependence of Colors," Pacific Philosophical Quarterly 68 (1987), pp. 249-264, p. 259. For this point, also see Berkeley, Principles I, 15, LJ II, 33-4.

11. Pitcher, p. 106.

22. E. G. Boring, Sensation and Perception in the History of Experimental Psychology, (New York: Appleton-Century-Crofts, 1942), p. 10.

33. The evidence from mathematical expressibility for the reality of a purported physical quality can vary with the nature of the empirical conditions specified by Carnap's fifth rule. (Recall that the fifth rule specifies under what empirical conditions differences in the values of magnitudes are equal.) This may show that the strength of the evidence for the physical reality of Aristotelian color, or some correlating quality, from the existence of a phenomenological color scale, is somewhat diminished. Compare the way Carnap's fifth rule applies for duration to the way it applies for Aristotelian color. For duration, we have very strong evidence that equal differences between the numbers of vibrations of a cesium atom correspond to equal real temporal differences, because the vibration of a cesium atom is a member of a very large equivalence-class of periodicities in nature, and there is only one such class. Our only basis for regarding the intervals in our phenomenological color scale as equal is the agreement of a large class of human perceivers. Consequently, the evidence that the duration scale picks out equal differences among real physical qualities is much stronger than is the evidence that the phenomenological color scale does so.

44. C. L. Hardin, Color for Philosophers, (Indianapolis: Hackett Publishing Company, 1988), pp. 36-52.

55. Hardin, pp. 59-67.