Aether as a referring term

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The aether has been used in the philosophy of science literature as a stereotypical example of a theoretical construct that played a major role in scientific development but was abandoned when it was found to be non-referring. This is generally ascribed to Einstein's development of special relativity but, in practice, the term and concept continued to be used by Einstein, and many others to the present day. In recent years the theory of the quantum vacuum has come to be seen as capturing the essence of the aether, accounting for phenomena of electromagnetism and gravitation, and having observable and useful consequences through the Casimir effect. This paper discusses the implications for the philosophy of science literature of the aether becoming accepted as a referring term, firstly in the theory of natural kinds, and secondly in studies that use it as an example of a non-referring term.

"the most important development to be expected in the near future concerning the foundations of quantum physics is a revival, in modern covariant form, of the ether concept of the founding fathers of the theory of light" (Vigier 1995)

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1. Introduction. Putnam's (2005) recent retrospections upon his seminal paper, *A philosopher looks at quantum mechanics* (1965) notes that he originally rejected Bohm's (1952) hidden-variable interpretation for leading to 'unacceptable causal anomalies' such as non-locality, but that the Aspect *et al* (1982) experiments shows that non-locality 'really exists.' Putnam's willingness in the light of empirical evidence to eliminate the scholastic axiom that good science cannot invoke *action at a distance* may be seen as a nice example of Kant's (1781) maxim that metaphysics has only a *regulatory* role not the *constitutive* one reserved for empirical studies. Its elimination is also consistent with Bohm's (1961) suggestion in an address to the British Society for the Philosophy of Science, *On the relationship between methodology in scientific research and the content of scientific knowledge*, that some of the criteria for good science needed to be relaxed. He speaks of them in terms of 'habits of thought' rather than metaphysical principles, but the examples he gives are of the same nature as the principles that Kant derived by deconstructing Newton's 'habits of thought.'

Putnam's rejection of Bohm's theories in the 1965 is not surprising in that they had not yet become part of the canon of good science (Myrvold 2003). In that era von Neumann's proof of the impossibility that any hidden variable theory could underlie quantum mechanics was still widely accepted. Hermann's (1935) critique of the proof was generally unknown (Jammer 1974), and Bell's (1966) critical analysis had not appeared. Bohm's theories were not assimilated into a sufficient breadth of ongoing research for them to be reasonably widely accepted as good science until the 1990s (Cushing 1994), and the rationale that Putnam used in rejecting them would have appeared reasonable to the majority of quantum physicists in the 1960s (and probably now).

Despite forty years progress in quantum physics, current debates about the derivation of quantum mechanics within an extended classical framework echo those of the 1960s. For example, Marshall and Santos (1997) argue that the Aspect *et al* (1982) results are a theory-laden artifact of modeling the light quantum as a particle, and that such experimental data has 'a consistent local realist explanation based on the unquantized Maxwell field.' Their model is based on the theory of the *quantum vacuum* (Pena and Cetto 1996; 1994) which is being used to

account for a wide variety of physical phenomena such as electromagnetic wave propagation, gravity, inertial mass, and so on, and is commonly termed the *aether* in much of the relevant literature. The situation for quantum vacuum theories now is much as it was for Bohm's theories forty years ago in terms of lack of widespread acceptance, but there are derived phenomena, such as the Casimir effect (Bordag, Mohideen, and Mostepanenko 2001), that have been demonstrated experimentally and are already been applied in other disciplines such as biology (Hameroff and Tuszynski 2004) and nanotechnology (Chan et al. 2005).

Thus, we may see another turn in the Putnam quantum mechanics saga with an aether-based theory being considered philosophically attractive and locality being reinstated. It would be speculative here, as would support for Bohm's theory in 1965, to attempt to make the case for such an outcome. The new aether theories will need to be further developed theoretically and empirically before they can gain acceptance as good science, but the range of scientific papers on the quantum vacuum and its applications already published in reputable journals makes such acceptance conceivable. What can be considered currently is the impact such acceptance would have on philosophy of science literature that has taken aether as a stereotypical non-referring theoretical construct, on par with *phlogiston* and *caloric*. There has been a genre of explaining how such luminaries of good science as Newton, Fresnel, Maxwell, Einstein and others, achieved what they did despite their use of the non-referring hypothetical construct of an aether. These involve issues of convergent realism and associated issues of reference significant for the philosophy of science. How do the accounts fare if the term aether is referential after all?

2. Aether as a natural kind. It would strengthen the discussion of the role played by the assumption of the non-referentiality of aether in the philosophy of science if one did not have to hypothesize a twin earth on which aether was a referential scientific construct, but could make a plausible case that it had been used as such on this earth for centuries, perhaps back to the Presocratics.

I will take the *nominal kind* definition of aether to be: an imponderable medium permeating all space and playing a major role in a range of cosmological phenomena. I note that additional properties have been ascribed to the aether by various scientists at various times, and that these define sub-kinds some of which would not now be taken to be referential.

I will take the *real kind* definition of aether to be: the quantum vacuum that arises in quantum mechanics as a consequence of the uncertainty principle, in that even 'empty' space manifests significant activity at the Planck level. I note that the physical manifestations of this activity predicted by Casimir in 1948, verified experimentally in the late 1950s and being used in nanotechnology in recent years, provide the kind of evidence normally required to support the case that the quantum vacuum is a referring term not just a hypothetical construct.

The link between the nominal and real definitions is the role that the quantum vacuum is playing in theories of electromagnetic propagation, gravitation and cosmology, including models of our universe, and others, as arising through quantum vacuum fluctuations. There is a major literature on these matters in professional journals which is too large to detail here but readily accessible through indexing services such as Scopus and the Web of Science.

3. Analysis of aether as a natural kind. If one accepts the above definitions and their relationship, then it is interesting to consider how the aether fares as a natural kind in relation to

discussion in the literature of the philosophy of science of natural kinds, their definition and their roles in various scientific disciplines.

The first component of Kripke's (1972) and Putnam's (1975) analysis of natural kinds is analogous to that for proper nouns in being based on rigid designation validated through a causal chain that links various usages. There is a fully connected network of such chains in the historic record of the use of the term aether in the scientific community (Whittaker 1989; Cantor and Hodge 1981; Kostrow 2001). Current usage of the term aether in the quantum vacuum literature cites the Mach/Poincaré/Einstein usage or the Fresnel/Maxwell/Hertz/Lorenz usage, and the former cites the latter in a rich network of linkages which reference the same notions as the nominal kind definition above, albeit with varying additional properties. These literatures also link to Newton's usage which itself has links to Aristotle, Plato and the Presocratics, unifying the rigid designation throughout the recorded history of science.

The second component, the essence-defining archetype that has not been part of the nominal kind definition but can be seen as fixing the reference underlying its usage, is the quantum vacuum as explicated in the relevant literature. Thus, Putnam's (1975) *normal form* for the meaning of aether is that it is: *syntactically* a concrete mass noun; *semantically* a natural kind complying with the nominal definition above; *stereotypically* having a varying constellation of other properties attributed by various scientists at various times; *extensionally* the quantum vacuum. The long and complex history of the aether and the late identification of the extension-defining laws exemplifies Putnam's remark that: "these laws are not usually known when the natural kind term is introduced, but require an indeterminate amount of investigation to discover" (Putnam 1983).

I have finessed Kuhn's critique of rigid designation models of natural kinds by capturing the essence of the significant usage of the term aether in the scientific literature at a fairly abstract level. The redubbing by different scientists adding properties to the stereotype, later modified by other scientists, creates a ship of Theseus situation, but the consistent compliance with my nominal kind definition shows that the hull is retained and that the ship is not changed into a house. The process can be modeled logically as the creation of sub-kinds, and is similar to those identified in the biological notion of a species (Wilson 1999), the psychological notion of a concept (Machery 2005), the philosophical notion of a natural kind (Dupré 2002), and so on.

Kuhn's discussion of force as a natural kind whose meaning derives from its role in a cluster of related kinds including motion, mass, weight and gravity is particularly relevant, because aether was another important term in that cluster for Newton. The first law establishes rectilinear motion as a stable state for undisturbed matter. The second defines force as anything which disturbs that state, and can be used to infer that circular or elliptical motion must involve a centripetal force. For untethered planetary motion, Newton ascribes the centripetal force to a gravitational attraction between the bodies involved related to their masses, and, to avoid action at a distance, hypothesizes the aether as the mechanism of that attraction. Newton's cluster introduces concepts of space, time, motion, inertial mass, gravitational and contact forces, weight and aether, all of which were problematic for him, and later for Mach, Poincaré, Enstein and others, and remain so.

Kuhn (1993) suggests that natural kinds in such a cluster are different from those defined through 'contrast sets,' i.e. mutually exclusive concepts under a common superordinate concept,

sub-types of a type. However, Newton's model of motion does involve such a contrast set with the superordinate concept being that of influences on rectilinear motion and the contrast set being the 'innate force of matter' (*vis insita*) and the 'impressed force' (*vis impressa*). It captures some his most important intuitions that there is one type of force acting on matter which resists change in motion, and another which induces it. *Vis insita* in his later writings became *vis inertiae*, and later developments removed the notion of force from inertia reserving that term for the impressed force. Similarly contrast sets underlie the notion of aether, the distinction that dates back to Anaxagoras and his experiments on air between ponderable and imponderable substances, and that emphasized by Aristotle between contact forces and those acting at a distance (Sambursky 1987). The concept of force defined in the second law became itself a superordinate type for various other sources of force such as electrostatic, magnetic, atomic, and it was presumed that there was either an aether associated with each or a common aether underlying all. In the absence of a unifying theory or the capability to manipulate the aether in an observable fashion, neither hypothesis could be tested until recently.

Boyd's (1999) analysis of species as a natural kind in biology that involves a homeostatic cluster of properties can be replicated for the aether and nicely captures the history of a major area of significant activity in the physical science as it does for the notion of species in the biological sciences. The cluster for aether includes considerations of properties supporting its role in gravity, electricity and magnetism with the two last becoming unified only post-Maxwell (Chalmers 1973), and all three becoming unified only post-Einstein (Bacinich 2003). It also includes notions stemming from Aristotle's rationale for rejecting action at a distance, that non-living systems were natural movers not self movers (Gill and Lennox 1994), which were adopted and extended by Newton who saw the aether as a mechanism by which God might interact with the universe, prompting his dispute with Leibniz about the aether being the sensorium of God (Koyré and Cohen 1961). Other somewhat imponderable media, such as caloric and phlogiston, have also been associated with the aether, but the homeostatic process eventually eliminated them as disturbances, although there remains a fringe literature on the aether's theological associations.

4. Aether as a non-referring term. Thus aether fits naturally into the literature on the analysis of other natural kind terms, and its usage exhibits a similar range of phenomena to that of species as a biological kinds. The common misconception that aether is a non-referring term seems to have arisen from Einstein's (1905) remark in his initial exposition of special relativity that the introduction of a "luminiferous ether" would be superfluous because his theory did not need an "absolute resting space" nor a "velocity vector to a point in empty space in which electromagnetic processes occur." Einstein was differentiating his theory from those of Mach and Lorenz (Miller 1981), but the notion began to circulate that he had disproved the existence of the aether. He later clarified that neither special nor general relativity had that consequence, and that general relativity needed an aether-like construct as a medium for the distortion of space (Einstein 1922; Kostrow 2001; Granek 2001). However, the misconception continued to propagate in the literature despite Einstein's later comments and Dirac's (1951) letter to Nature noting that "the aether is no longer ruled out by relativity, and good reasons can now be advanced for postulating an aether. ... we may very well have an aether, subject to quantum mechanics and conformable to relativity, provided we are willing to consider a perfect vacuum as an idealized state, not attainable in practice."

It would be interesting to know more about the process and timing of this propagation. Millikan (1924) uses "ether" as a referential term in his Nobel Lecture. Eddington (1946) notes that "I do not think that the modern fashion of calling the aether 'empty space' is conducive to clearness, and I shall here keep the classical term." He goes on to explain that the "most crucial difference between matter and aether (which are both carriers of energy tenors, strains, etc.)" is that "the former provides a reference system for velocities and the latter does not". These remarks suggest the misconception may have arisen through the popular literature on relativity theory taking a change in terminology to be evidence of change in referentiality. For example, Goldberg's (1984) *Understanding Relativity* when describing the properties of the aether notes "To you and me, it may seem extraordinary that natural philosophers were willing to accept the possibility of the existence of such a substance", and goes on to group it with phlogiston and caloric.

The ruminations of Newton, Mach, Poincaré and Enstein over the nature of the aether, and the frustrations they express over the elusiveness of the notion parallel those over the notion of species in biology. They did not have an extension-defining term such as H_2O or the gene, and the quantum vacuum that now fills that role through processes at the Planck level was not, and is not, an easy notion to model. The parallel with the gene suggests also that even the availability of that definition will leave many issues unresolved (Falk 1986), It was natural for many to wish that the issue of the aether had been resolved by Einstein, so that it could now be classified as a historic construct that had played a role in outdated theories but could now be dropped. The role that the physical phenomena arising from the quantum vacuum have played in establishing the 'reality' of the aether is also interesting. The observable consequences of the Casimir effect and their application in empowering new technologies satisfy needs not only to explain and visualize a theoretical construct (Miller 1984) but also, through instrumentation, to view its effects (Galison 1997) and be able to use them in a Baconian framework for the achievement of human purposes.

5. Consequences of assuming that aether is a non-referring term. The preceding discussion makes a case that aether is a referring term that provides a serious and interesting case history for various theories of natural kinds. This section examines some examples of studies that have presupposed that aether is a non-referring term in their discussions of various aspects of the philosophy of science.

In some studies one would expect there to be no consequences because aether has been used as a stereotypical 'non-referring term that has played a role in science,' and could be replaced by that description without detriment to the argument. In others where a significant actual example is required, some other case that is less likely to be problematic might serve such as caloric or phlogiston, although some arguments might be weakened by the shorter life spans and lesser roles of these constructs. For studies specific to gravitational or electromagnetic phenomena the presupposition that the use of the aether construct was erroneous might possibly lead to different conclusions.

Marchildon's (2006) recent rebuttal of Bub's (2005) argument that Bohm's *trajectories* construct should be abandoned by analogy with the dropping of the aether construct, because neither has observable consequences is particularly interesting because both sides accept that the aether is non-referential, and the clarity of the arguments makes both the basis for this and the consequences clear. Bub quotes a 1919 article by Einstein in which he distinguishes

'constructive' theories that reduce complex phenomena to simpler underlying hypothetical processes from 'principle' theories that commence with general characteristics of natural processes that give rise to mathematically formulated criteria which the mathematical representations of the processes have to satisfy. Einstein saw special relativity as a *principle* theory and the aether as a component of a *constructive* theory playing no role in special relativity. Bub argues by analogy that Bohm's theory is a *constructive* theory based on unobservable trajectories and proposes instead a *principle* theory based on the flow of information. Marchildon counters that there is a difference between the aether and Bohmian trajectories because Maxwell's equations allow the electromagnetic field to be self-sustaining whereas information requires a carrier. Bub can presumably counter by noting that this objection presupposes a *constructive* theory whereas his is a *principle* theory.

If the Casimir effect is seen as making the quantum vacuum *qua* aether observable then both sides of the argument have to change. Bub's is weakened because the aether is no longer "excess empirical content" and this raises the question of whether Bohmian trajectories may eventually become construed as having been 'observed' through some associated effect. His use of Einstein's dichotomy to argue that Bohm's is a *constructive* theory and his own is a *principle* theory remains valid, and can be seen as an argument against the necessity of reductionism, one common in other disciplines such as psychology. Marchildon's argument that information requires a physical carrier can be seen as analogous to Newton's that gravity requires a medium.

Overall, the impact of the assumption of the aether being non-referential obfuscates the Marchildon-Bub discussion which is otherwise a very clear statement of the implications of choosing either side of Einstein's *constructive—principle* dichotomy. That dichotomy is itself a nice example of one of Holton's (1973) oppositions between themata, *reductionism—holism*. From a holist perspective the formulation of theory that saves the phenomena is all that is needed, and no constructs should be introduced in that theory unnecessarily. From a reductionist perspective the derivation of the theory from 'deeper' principles is desirable. It should be noted that holism was not necessarily Einstein's preferred pole of his dichotomy. His critique of his own theory in 1908 notes that "a physical theory can be satisfactory only when it builds up its structures from elementary foundations" (Brown 2005). In 1905 he noted that the aether construct was not required in special relativity from a holist perspective, and in 1922 that it was needed as a carrier of the distortions of space in general relativity from a reductionist perspective. Whether the aether is referential is not logically relevant to those positions.

Laudan's (1984) critique of Putnam (1978) analysis of convergent realism is again one where both parties assume that the aether is a non-referential term. For Putnam aether becoming a referring term just moves it from one side of his case to the other, as an example of convergence in scientific knowledge rather than an exception that shows that convergence may involve the rejection of a few non-viable constructs such as phlogiston or caloric. Laudan takes the aether a major example of a construct that played a significant role in the development of significant scientific theories but turned out to be non-referential, and is an important counter-example to Putnam's arguments for convergent realism. Aether is no longer available as such an example but Laudan can cite caloric or phlogiston instead. However, both examples are of dubious value as the constructs can be interpreted within the frameworks of the theories that replaced them. Clausius showed that Lavoisier's caloric and Joule's kinetic theory were compatible if one interpreted the conservation of heat as the conservation of energy (Cardwell 1971)—the term

was not needed but the underlying construct was referential. Lavoisier showed that phlogiston is interpretable as the absence of oxygen and, given the logical problems of ontologies of absence, this is a better construct—one does not need to get into issues of whether a hole can be construed as referential.

6. Conclusions. It is unfortunate that the aether has become a stereotypical example of a non-referring term in the philosophy of science literature since that appears to be a misconception. The primary impact has been to draw attention away from the richly documented history of one of the most difficult constructs in the physical sciences that has been studied by many major scientists back to the beginnings of science itself, wherever we place them.

In particular, the science of the aether is significant as a venue where realist and constructivist notions can be critically compared. For most of its history it was a construct deriving from metaphysical heuristics rather than empirical data, but it played an important role in the development of models of such data that led to well-established theories. It was accepted as the carrier of the properties of the vacuum that had precise mathematical properties but no observable presence, but then the term fell into disuse because the carrier per se played no role in the theories. The theories themselves became regarded as irreducible. Now that quantum vacuum theory is providing reductionist foundations for a unified theory, and the Casimir effect is leading to observable phenomena, the aether is becoming seen as referential, as 'real.'

But what is the difference between a construct and reality for phenomena at the Planck level? One account might be that metaphysical principles are ultimately constitutive, not in a transcendental sense, but more in a social representations sense, that the themata we accept as underlying good science shape the acceptable form of that science. The principle of locality is a reductionist heuristic that encourages us to account for phenomena through mechanisms that connect them through space and time. The principle of causality requires that the connections be forwards through time. At the macro level these may be more in the nature of laws than heuristics. At the micro level Bohm's theory suggests we violate locality, Hermann's that we violate causality, and quantum vacuum theory that we violate neither. It is conceivable that all three theories, and others, will prove to be equally empirically adequate, understandable, computationally tractable, and so on, and that the only difference will be the underlying metaphysics.

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