"Charge without Charge" in the Stochastic Interpretation of Quantum Mechanics

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ABSTRACT

In this note I examine some implications of stochastic interpretations of quantum mechanics for the concept of "charge without charge" presented by Wheeler and Misner. I argue that if a stochastic interpretation of quantum mechanics were correct, then certain shortcomings of the "charge without charge" concept could be overcome.

1. Introduction

Several decades ago, John A. Wheeler [1955] proposed an intriguing idea about the relationship between electric charge and the topology of space. Subsequently, Wheeler and Charles W. Misner developed this idea further ([Misner & Wheeler, 1957]; [Wheeler, 1957]; [Wheeler, 1962]; [Wheeler, 1968]; [Misner et al., 1973]) and characterized it as "charge without charge" [Misner & Wheeler, 1957]. (In the present paper I abbreviate "charge without charge" to CWC.) The gist of the idea of CWC is that charge can arise from the topological trapping of electric field lines in wormholes. A wormhole containing such trapped fields behaves as though each of its mouths had an electric charge. A charged wormhole mouth of this kind can serve as a classical model for a charged particle ([Wheeler, 1962]; [Misner & Wheeler, 1957]; [Wheeler, 1968]; [Misner et al., 1973]), while a quantum mechanical charged particle might possibly be identified with a collective disturbance in the topology of space, which is expected to contain wormholes of Planck size, $\sim 10^{-35}$ m ([Wheeler, 1957]; [Wheeler, 1968]; [Misner et al., 1973]).

The idea of CWC played a large part in a major project of Wheeler's: the reduction of all matter to the geometry and topology of spacetime, in the spirit of general relativity's reduction of gravity to spacetime curvature ([Wheeler, 1957]; [Wheeler, 1968]; [Misner et al., 1973]). Wheeler's geometric view of matter, and the CWC concept in particular, were the subjects of significant research and speculation from the 1950s through the 1970s and beyond. These ideas are less often championed today, partly because of the conceptual difficulties besetting CWC (see below) and partly because of the widespread acceptance of a different view of matter, namely string theory.

In this essay, I will not argue for or against CWC as a model of charge. Instead, I will explore a different, and seemingly peripheral, question: I will ask about the implications of a particular interpretation of quantum mechanics for CWC. The interpretation that I have in mind here is not the widely accepted Copenhagen interpretation, but the *stochastic* *interpretation* of quantum mechanics. Before beginning this project, I should say a few words about the stochastic interpretation of quantum mechanics and why it is interesting. (Readers who desire a historical introduction to the stochastic interpretation are referred to [Jammer, 1974].)

In spite of the wide acceptance of the orthodox Copenhagen interpretation of quantum mechanics, the question of the correct way to understand quantum mechanics still has not been conclusively answered. Among the available alternatives to the Copenhagen interpretation are the many-worlds interpretation (see [DeWitt & Graham, 1973]), which is well-known today, and the stochastic interpretation (see, for example, [Nelson, 1985]). The central idea of the stochastic interpretation is the view that the uncertainty in a particle's observable properties, such as position and momentum, is not due to the particle's lack of a sharp trajectory, but rather to the particle's following a random trajectory which is not directly observable by us. This interpretation, at least in some of its versions, is able to avoid the standard objections to local hidden variable theories (see [Nelson, 1985]; [Jammer, 1974]; for a discussion of these objections, see [Shimony, 1988]). The stochastic interpretation has been a subject of active recent research; the peer reviewed literature on that interpretation is large and apparently still growing. (For a few of many available examples of this literature, see [Pavon, 2001]; [de Angelis, et al., 1986]; [Nagasawa, 1993]; [Garbaczewski, 1990]; [Vigier, 1989]; [De Angelis & Jona-Lasinio, 1982]; [Lehr & Park, 1977]; [de la Peña and Cetto, 1975]; [Nelson, 1985]; [de la Peña-Auerbach, 1971]; [de la Peña-Auerbach, 1969]). I will not discuss the stochastic interpretation in depth here; instead, I will refer the reader to the literature on this topic.

In this note I will not argue for or against the stochastic interpretation, nor will I criticize or defend CWC. (Least of all will I try to argue the merits of CWC versus other views of charge, such as the one offered by string theory.) My sole aim here is to explore the logical interrelationships between two physical ideas: CWC and the stochastic interpretation of quantum mechanics. In the end, I will conclude that CWC would be less problematical, and less troubled by conceptual difficulties, if the stochastic interpretation of quantum mechanics were right. Beyond this, I will leave the reader to draw his or her own conclusions.

2. Difficulties with "Charge without Charge"

The idea of CWC, though intriguing, suffers from several difficulties, which I will now list. Misner and Wheeler have tried to address some of these problems (see [Wheeler, 1968] and [Misner et al., 1973], which discuss objections (1) - (3) below).

(1) Based on the principles of quantum theory, we expect spacetime to undergo large metric fluctuations, and perhaps topological fluctuations (sometimes called "spacetime foam"; see [Visser, 1994]), at scales comparable to the Planck length. These fluctuations prevent any straightforward identification of wormhole charge with real particle charge.

(2) We do not yet understand the role of topology change in spacetime physics (see in particular [Visser, 1994]).

(3) It is difficult to find a place for spinor particles in a model of matter based entirely on the geometry of manifolds. (Actually, this is a problem with the geometric conception of matter and not specifically with CWC, but it reflects badly on CWC.)

(4) We do not yet understand the dynamics of spacetime geometry at the Planck scale. (This, of course, is a general problem that affects all ideas and speculations about physics at the Planck scale.)

(5) According to the topological censorship theorem, the wormhole would pinch off and the throat would be destroyed. (This objection is covered in [Visser, 1994]. However, it is not a fatal objection, because quantum effects could forestall the collapse [Visser, 1994].)

(6) At the time of the writing of this paper, the existence of wormholes on any scale still remains entirely unconfirmed. (This obvious objection is not a very good one, because our failure to find astronomical wormholes says little, one way or the other, about the likelihood that quantum wormholes exist.)

The ideas of the stochastic interpretation of quantum mechanics may place CWC in a somewhat better light. I will now suggest some ways in which points (1) - (4) might be addressed within the framework of the stochastic interpretation.

(Point 1) *The stochastic interpretation might be able to "tame" the spacetime foam.* Most papers on the stochastic interpretation apply the concepts of stochastic mechanics to particle motion. However, the stochastic interpretation also has been applied to the quantization of fields ([Guerra & Loffredo, 1980]; [Namsrai, 1986]). There is no obvious reason why the stochastic interpretation could not be applied to spacetime geometry. Indeed, this has been done by Namsrai [1986], and in a different way by Prugovečki [1984]. (See also some of the references in [Namsrai, 1986], p. 9.) Smolin [1986] has suggested that such an interpretation may become necessary for the proper treatment of certain problems about black holes. A stochastic version of spacetime physics, if constructed by analogy with typical theories of stochastic particle mechanics, requires us to think of spacetime geometry as subject to random fluctuations too rapid to be observable to us by presently available means. In a theory of quantum gravity based on a stochastic metric, if the time scale for the fluctuations were at least as large as the Planck time (~ 10^{-43} s), then the fluctuations at the Planck scale would be much weaker than expected (see [Sharlow, 2004]). It remains to be seen whether a theory of this sort could be formulated. (One possible way to do this, though not an actual theory, is suggested in [Sharlow, 2004]).

The idea of using the stochastic interpretation to solve problems in gravitational physics is not new. Already I have mentioned the work of Namsrai [1986], who developed a theory of stochastic spacetimes and a stochastic metric and applied these ideas to fundamental problems in physics. Prugovečki [1984] developed a theory of "stochastic quantum mechanics" in which spacetime has a built-in stochastic structure. Smolin [1986] has suggested that quantum mechanics is likely to fail in the presence of sufficiently strong gravitational fields, and that some sort of stochastic mechanics might have to take the place of quantum mechanics in those situations.

(Points 2 and 4) *The stochastic interpretation raises new possibilities for small-scale spacetime structure.* By itself, the stochastic interpretation does nothing to alleviate our ignorance about how spacetime behaves in the small. However, it offers us some fresh suggestions about how spacetime *might* behave in the small. Specifically, if we had a stochastic model of spacetime geometry which undergoes jumps on a time scale at least as great as the Planck time (see, for example, [Sharlow, 2004]), then the spacetime geometry between the jumps might be smooth. In such a spacetime model, some of the concepts of the geometry and topology of manifolds would be applicable to spacetime even at the Planck scale (!) -- the spacetime foam notwithstanding. Within the context of a spacetime model of this sort, we can talk meaningfully about Planck-scale wormholes and other Planck-sized particle-like objects -- something that might not be possible within other pictures of quantized spacetime in which the manifold structure is inapplicable at the Planck scale. If the stochastic interpretation of quantum mechanics holds, then such particle-like objects will seem to behave like quantum mechanical particles when viewed at a resolution much coarser than the Planck scale. They may obey relativistic wave equations for which there are stochastic models; such equations include the Klein-Gordon equation ([Pavon, 2001]; [Lehr & Park, 1977]), the Maxwell-Proca equation ([Garuccio & Vigier, 1981]; see also [Ord, 1997a] for a special case), and the Dirac equation (see [de la Peña-Auerbach, 1971]; see also [de Angelis, et al., 1986], [Ord, 2002] and [Ord, 1997b] for the (1+1)-dimensional case).

(Point 3) *The stochastic interpretation may provide a way to construct objects of spin 1/2 within a spacetime that lacks any intrinsic spinorial structure.* According to a result of de la Peña-Auerbach [1971], a rotating particle in a suitable formulation of stochastic mechanics can have a quantized angular momentum that takes on both integral and half-integral values. de la Peña-Auerbach further shows that such a particle can be described by a spinor wave function. It is well known that half-integral orbital angular momentum is impossible for a particle in a central force. However, as de la Peña-Auerbach points out, this impossibility depends logically upon the assumption that only two Euler angles are needed to describe the orientation of the system -- an assumption that fails in the stochastic model in question. This suggests that spin 1/2 could appear in physical systems even without any preexisting, "built-in" spinorial structure in spacetime. It remains to be seen whether the spinor quantities obtained via this route can somehow be explained or visualized in terms of orientation-entanglement relations [Misner et al., 1973]. (Perhaps we might think of the emergence of spin 1/2 in this context as a kind of spontaneous breaking of the rotational symmetry of space.)

I approach these ideas with great trepidation, because (as de la Peña-Auerbach already pointed out in [1971]) the idea that spin angular momentum may be due to a real rotation is extremely unpopular. However, this idea is perhaps less upsetting when combined with CWC, since CWC already forces us to regard particles as based on objects (wormhole mouths) that are extended and possibly spinning.

3. What Kinds of Wormholes Might There Be?

For any study of CWC, it is helpful to know what kinds of wormholes might exist. (Of course, the existence of any wormholes at all remains speculative, but nevertheless one can consider the mathematical and physical possibilities.) Normally, one thinks of a wormhole as a "throat" in spacetime, with mouths that are black holes. However, other kinds of wormholes, whose mouths are not black holes, are mathematically possible. A simple mathematical construction allows one to add wormholes to a manifold by means of a "cut-and-paste" operation [Visser, 1994]. A wormhole constructed in this way need not be much like an astrophysical black hole, and may even be traversable. Probably it would be able to trap field lines just as a wormhole of the customary sort would do.

A wormhole of this "cut-and-paste" sort may have various values of spin and mass. In the physics of classical wormholes, there has been much discussion of wormholes threaded with negative mass (see [Visser, 1994] and some references therein). Perhaps one can envision a positive-mass wormhole mouth with enough negative mass added to cancel out the mass of the black hole -- but with the hole and/or the negative mass having nonzero angular momentum, to give a net nonzero angular momentum. Such an object, if it could exist at all, would have zero mass and nonzero spin. Here we reach the far edge of speculation; I do not wish to proceed further. My point is that we cannot casually rule out the possibility of a massless but spinning wormhole mouth. To know whether this is a real possibility, we would have to know much more about quantum gravity -- especially about the nature of negative energy.

4. Trapped Fields from Stochastic Mechanics?

In the classical CWC scenario, a wormhole has a trapped classical electromagnetic field, leading to effective charges at the wormhole's two mouths. Intuitively, the reason that such trapping can happen is that electric lines of force, in the absence of charge, never end ([Wheeler and Misner, 1957]; [Wheeler, 1957]; [Wheeler, 1968]; [Misner et al., 1973]). Since the endlessness of electric lines of force is a mathematical consequence of the source-free Maxwell's equations, it follows that this kind of trapping can occur for any field that obeys those equations. In a spacetime which contains particles in stochastic motion, if there were a classical Maxwell field that is *not* stochastic, then there could be a wormhole that traps that field. This would be possible even if the mouths of the wormhole were in stochastic motion. Even if a wormhole mouth had its motion disturbed abruptly every so often, the rest of the wormhole mouth's history would consist of stretches of the ordinary history of a wormhole mouth in a manifold. Hence there is no reason why a wormhole mouth should not be able to hold on to a trapped electric field, even if the wormhole's mouths are in stochastic motion.

If the stochastic interpretation of quantum mechanics is correct, then a wormhole is not limited to trapping a classical Maxwell field. *It can just as easily trap the Maxwell field that describes the stochastic motion of a spin 1 particle.* To see how this can happen, consider the following *gedankenexperiment*. Imagine a wormhole in a spacetime that also contains many very small spin 1 massless particles, each of which has no trapped fields. These spin 1 particles undergo jumps of the sort required by the stochastic interpretation. The mouths of the wormhole also undergo stochastic jumps. Imagine that there is an observer sitting on one mouth of the wormhole. Assume that this observer is sufficiently coarse-grained to be unable to make observations at a time resolution comparable to the time scale for the stochastic jumps of the spin 1 particles. If the stochastic interpretation of Maxwell's equations is correct, then the spin 1 particles will appear to be quantum mechanical particles whose motion is described by a Maxwell field. Thus, the observer will find himself surrounded by a Maxwell field. However, the observer will *not* find his own wormhole mouth to be describable by a field. Because he is comoving with the mouth, he will see the mouth as a localized object that remains at rest. Thus, the observer on the wormhole mouth will find himself in a spacetime containing a wormhole mouth (on which he sits) and a Maxwell field. Likewise, a similar observer sitting on the other mouth of the wormhole will find the object he sits on to be stationary, and will find that spacetime contains a Maxwell field. But if there is a wormhole and a Maxwell field, then there is a possible state of the wormhole with a trapped Maxwell field. The fact that one mouth of the wormhole is in stochastic motion relative to the other mouth cannot change this (recall my earlier remarks about the topology of the classical Maxwell field, which is applicable to this new case as well).

In hindsight, this conclusion is not too surprising. Certainly some of the stochastic jumps that the spin 1 particles make will take them into, or out of, the wormhole. This passage of particles through the wormhole must be the small-scale phenomenon that corresponds to the larger-scale phenomenon of field trapping by the wormhole.

Of course, the preceding handwaving arguments do not prove rigorously that a wormhole can trap a Maxwell field associated with the stochastic motion of spin 1 particles. Only a detailed analysis of the stochastic mechanics of spin 1 particles in curved spacetime could do that. However, our intuitive argument does make that kind of trapping plausible. The conclusion of that argument is of limited validity at best; it might not hold in situations in which the observer on the wormhole does not see the spin 1 particles as a field (for example, if there are very few such particles, making the field very weak). Nevertheless, barring these situations, it seems likely that there can be CWC even if the Maxwell field arises from the stochastic motion of particles.[1]

The question of the quantization of charge of this kind is beyond the scope of this paper. However, it is worth noting that stochastic mechanics sometimes gives rise to quantization in systems which one would not expect to be quantized.

The upshot of all this is that we can get a kind of CWC by assuming the existence of wormholes and spin 1 particles obeying suitable conditions and subject to a stochastic interpretation of quantum mechanics. This strategy would work even if the spin 1 particles were themselves small-scale geometric entities of some sort (perhaps even the massless holes with spin mentioned in Section 3). Moreover, the "electromagnetic field" in this scenario already has particles associated with it.

5. Concluding Remarks

We have seen that the stochastic interpretation of quantum mechanics gives the concept of "charge without charge" a surprising new look. Some of the conceptual problems facing CWC are softened, and we gain an interesting new model for electromagnetism (the stochastic model of Maxwell's equations) that might be able to do duty in CWC. Most of the shortcomings of CWC discussed in Section 2 begin to look less like limitations of CWC itself, and more like difficulties caused by trying to understand CWC with the help of the Copenhagen interpretation.

CWC is not today's most popular candidate for a physical model of charge. However, the idea of CWC still may be of interest, because (*pace* some string theorists) the question of the ultimate structure of matter, and of the ultimate nature of charge, has not yet been conclusively settled. The question of the correct interpretation of quantum mechanics also remains unsettled. In view of the known connection between black hole physics and the stochastic interpretation [Smolin, 1986], the study of ideas about microscopic wormholes within the context of a stochastic theory is bound to be interesting, and perhaps even fruitful.

Notes

1. In the preceding argument, I assumed implicitly that the stochastic jumps of the wormhole mouth are slower than light. In some models of stochastic mechanics, the jumps take place at the speed of light ([Ord, 2002]; [Ord, 1997a]; [de Angelis et al., 1996]; [Lehr & Park, 1977]). I do not think that this destroys the argument; one can take the v = c case as a limiting case, and particles still can enter and pass through the wormhole.

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