PHYSICAL REVIEW D VOLUME 29, NUMBER 8 15 APRIL 1984

Comments

Comments are short papers which comment on papers of other authors previously published in the **Physical Review**. *Each Comment should state clearly to which paper it refers and must be accompanied by a brief abstract. The same publication schedule as for regular articles is followed, and page proofs are sent to authors.*

Comment on "Observer dependence of quantum states in relativistic quantum field theories"

I. Bloch
Department of Physics and Astronomy, Vanderbilt University, Nashville, Tennessee 37235
(Received 1 November 1982)

In response to Malin's recent paper it is suggested that the important aspect of timing in relativistic descriptions of position determinations is the timing with which a pure state is converted to a mixture, rather than the timing of the mixture's reduction to a new pure state; this suggestion removes some of the subjectivism that Malin finds in quantum states. It is suggested also that viewing quantum mechanics as a branch of psychology raises more questions than it answers.

Malin,[1] in a paper with the foregoing title, concludes that quantum states describe, not the world, but observers' knowledge of the world. In reaching this conclusion, Malin uses the work of earlier authors who claim[2] and others who dispute the claim[3] that a relativistic description of a position determination entails a collapse of the wave function on a constant-time hypersurface in the Lorentz frame in which the description is used. This mode of collapse produces noncovariant differences between wave functions in different frames. Malin construes these differences as observers' differences of opinion, and exacerbates the observers' disagreement by placing them at various distances from the detector, thus delaying their knowledge of experimental results.

This interpretation of Malin's paper as pertaining to human states of mind is supported by his use of such words as "knowledge" and by some of his comments, but other interpretations are conceivable. The word "observer" could be taken to mean "measuring instrument," and "knowledge" could be taken to mean "recorded results of measurements." Indeed, one of Malin's sentences suggests an even more fundamental shift of interpretation: "The phrase 'an observer's knowledge of a system at time t' is taken to mean 'the information about the system that can be available at the spatial origin of a given frame of reference at time t by appropriate lightlike signals'." If this sentence is construed as a definition, it can be used to replace all references to observers and knowledge by equivalent references to Lorentz frames and signals.

It seems to me that either of the alternative interpretations of Malin's paper would trivialize it, reducing it to a restatement of previous work.[2] The paper has new and interesting content only if it is truly about the knowledge of human observers. Accordingly, this is how I interpret it, and I construe the quoted sentence as merely describing the mode of knowing that Malin chooses to discuss. There are other ways of acquiring information and other ways of interpreting the information once it is acquired. I suggest below some alternative points of view.

One should distinguish the different changes of a wave function occasioned by an observation. The first, describable by a Schrödinger-type equation, is the sudden conversion of a particle's pure state into a mixture through coupling of particle states to apparatus states. It is this conversion that occurs instantaneously. The second change is the selection of one component of the mixture as the correct one, whether this occurs through intervention of a mind or through a more objective irreversible process that makes a record of the experimental result. Admittedly this reduction has not been very well analyzed, and some physicists see in it an essential role for mind in physical processes—an opinion that others dispute. In any case, the failure of covariance comes from the first process, in which no one has suggested a role for a human observer.[4]

The time delay that Malin assumes between a detection event and an observer's knowledge of the event seems to belong in a different category from the breakdown of covariance. Even in nonrelativistic quantum theory one can assume that the observer (or recording device) is influenced by the detection of a particle only long after the particle has departed from the detector—perhaps because of distance, or because a tortoise was used to carry the information, or because the observer simply did not bother to look at the record until Monday morning. Even when the observer is continuously watching a detector, the time delay in the instrument's action and the delay of understanding in the observer's mind guarantee that the detected particle has departed or been absorbed milliseconds before the observer realizes that it has been detected. I believe that in all such cases the observer concludes that, starting at the instant of detection, the particle's wave function was what he has subsequently found it to have been. The collapse occurred right away, but the observer's knowledge of the collapse was delayed, perhaps by the observer's own choice. If one takes the collapse of the wave function to occur only when the observer becomes aware of the result of a measurement, one already encounters in nonrelativistic quantum mechanics the observer dependence of state vectors that Malin finds in the relativistic theory. But this interpretation is unnecessary.

In general, it seems excessively complicated to interpret state vectors as embodying someone's knowledge of systems rather than the states of the systems themselves. If one distinguishes *knowledge* from mere *belief* by its being true or well founded, one is thus assuming that there is an objective criterion for correctness of belief—and then one should seek state vectors that conform to that criterion and thus represent the true state of the system. Lacking such a criterion (as Malin apparently assumes we do) one must accept any state vector that correctly embodies someone's belief, regardless of its conformity with data. If someone has false beliefs, the correct state vector for that person to use is one that embodies those beliefs. It seems to me that such an interpretation of state vectors raises more questions than it answers.

If one rejects Malin's explanation of the problem discussed in Ref. 2, the question remains whether there is an inconsistency in relativistic quantum theory and, if so, how it should be resolved. This is too large a subject to be discussed in a short Comment. Let me suggest simply that a given set of data does not have to be in one-to-one correspondence (up to a Lorentz transformation) with a state vector. The set of equivalent state vectors is larger than that, and includes some with differences that cannot be produced by Lorentz transformations.

---

[1] S. Malin, Phys. Rev. D 26, 1330 (1982).

[2] I. Bloch, Phys. Rev. 156, 1377 (1967); Y. Aharonov and D. Z. Albert, Phys. Rev. D 21, 3316 (1980); 24, 359 (1981).

[3] K. E. Hellwig and K. Kraus, Phys. Rev. D 1, 566 (1970).

[4] It may seem strange that a relativistic wave equation (like the Dirac equation, for example) can produce an instantaneous (thus noncovariant) change from a pure state to a mixture. In brief, it happens as follows: Let H_0 be the covariant Hamiltonian of the noninteracting particle and apparatus, and let $PKP\,\delta(t)$ be the instantaneous interaction of particle and apparatus. Here P is the projector into the counter volume, and K depends, in general, on both particle and counter variables. We do not try here to specify the details of this Hamiltonian, but assume that it can be made covariant, even though P and $\delta(t)$ refer to a particular Lorentz frame. We assume an initial uncorrelated state: $\psi(0^-)=A_0(0)S_i(0)$, where A_0 is the state of the detector in which it has not counted and S_i is the initial state of the particle. Now the time-development operator

$$\exp\left[-i\int H dt\right] ,$$

where $\hbar=1$, when integrated from immediately before to immediately after $t=0$, has a contribution only from the interaction term, so that the state at $t=0^+$ is

$$\begin{aligned}\psi(0^+) &= e^{-iPKP}\psi(0^-)=\psi(0^-)+P(e^{-iPKP}-1)P\psi(0^-)\\ &=(1-P)A_0(0)S_i(0)+Pe^{-iPKP}A_0(0)PS_i(0)\ .\end{aligned}$$

Here the first term contains the part of the particle state lying outside of the counter, still correlated with the counter's quiescent state—both unaffected by the interaction—and the second term has the part of S_i in the counter, correlated with whatever counter state the interaction has produced. Although the interaction has not affected anything outside of the counter, that part of the particle's wave function has become part of a mixture because the part of the wave function in the counter has become correlated with a counter state. If the object that interacts with the particle has no dynamical variables, K will depend solely on particle variables, and the state $\psi(0^+)$ above will still be a pure state of the particle. This would be the case of a *potential* that is on instantaneously, but it would not encompass observations.