Title: The Framework of Effects

Date: May 27, 2008 04:00 PM

URL: http://pirsa.org/08050043

Abstract: The focus of this talk is a particular feature of the statistical behavior of elementary particles, simple composite systems of them and the quantum probability theory to which this behavior gives rise. The standard interpretation of a generalized probability theory of the sort found in quantum mechanics is that its probabilities are probabilities of propositions belonging to particles, where a proposition belongs to a particle if its constituent dynamical property is a possible property of the particle. The feature of interest is the fact that there exist simple systems and finite combinations of propositions belonging to them for which no two-valued measures are possible. I will argue that quantum probabilities are not satisfactorily interpretable as probabilities of propositions belonging to particles, and that such an interpretation is possible only when the propositions to which probabilities are assigned form (an algebraic structure which is homomorphic to) a Boolean algebra. The idea I will develop is that the probabilities of quantum mechanics are probabilities of â€œeffects,â€• probabilities of the traces of particleinteractions with objects and processes that are epistemically accessible to us. I hope to make it clear that such a view is not committed to any kind of anti-realism about the micro-world, that its mildly instrumentalist flavor is not a defect but a strength, and that it illuminates at least one otherwise paradoxical feature of quantum mechanics.

1. The problem of hidden variables.

By *the problem of hidden variables* I mean the problem of understanding the conceptual innovation exhibited by the possibility of physical systems whose associated propositions exemplify the Kochen-Specker theorem.

There are finitely many direction-dependent propositions belonging to such systems—propositions of the form,

(*) the square of the spin in the direction $\alpha \neq 0$—,

which are so related that there is no generalized two valued measure definable on them.

The propositions are arranged in families of Boolean algebras of which the maximal families are generated by three atomic propositions, each associated with one of three orthogonal directions x, y, z of ordinary physical space.

To each such family there corresponds an operational procedure which is interpretable as offering a means of detecting which of the propositions of the Boolean algebra are true and which are false.

The application of every such test procedure determines that exactly one of the propositions

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for $\alpha = x, y, z$ is false, and exactly two are true.

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The application of every such test procedure determines that exactly one of the propositions (*) the square of the spin in the direction $\alpha \neq 0$ for $\alpha = x, y, z$ is false, and exactly two are true.

But on the hypothesis that the families of propositions are related in the way specified, it is logically impossible that there should be an assignment of truth values to all the (finitely many) families of such propositions that respects this observation as we run through all the finitely many triples of directions required for the proof of the theorem.

2. Three desiderata for a *natural* interpretation of the Kochen-Specker theorem.

Determinacy: Every proposition which attributes a possible dynamical property to a particle (i.e. every proposition which belongs to a particle) is determinately true or false. In particular, if *P* is a disjunction of propositions, each disjunct of which attributes a possible point value of a dynamical variable, and if the disjuncts exhaust all possible point values, then if *P* is true, exactly one of its disjuncts must be true.

Objectivity: Dynamical properties are indicated by a variety of experimental conditions and operational criteria. The methodological basis for objectivity rests on two considerations:

(*a*) every property requires a clear physical criterion for saying when it holds and when it fails to hold.

(*b*) an objective property is conceptually independent of the procedures for accessing it: the same property should be accessible in different measurement contexts, and by alternative measurement procedures.

If the notion of a property is tied to just a single operational procedure, we renounce this aspect of our concept of objectivity, since this is tantamount to abandoning the idea that the *same* property may be presented differently.

Accessibility in a variety of experimental contexts is not only largely constitutive of what we mean by the objectivity of properties, it is also what supports standard forms of counterfactual reasoning about them, and this too is an essential component of the objectivity we associate with physical properties.

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Observer independence: The reality that attaches to particles is an observer-independent reality; this holds as well for their physically important properties. The observer-independence of particles is so closely tied to the objectivity of their properties and the determinacy of propositions involving them, that it is undermined when these desiderata are called into question.

3. Contextuality.

Consider the following orthogonal triples of directions in E^3:

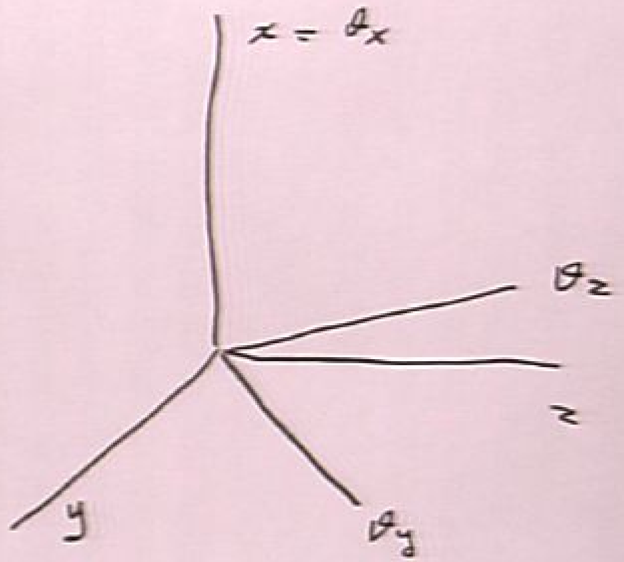

Figure 1

Orthogonal triples of directions in E^3

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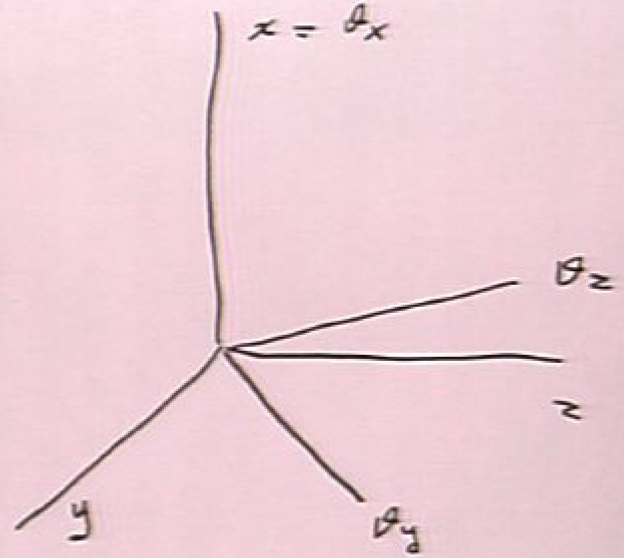

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where $x = \theta x$ but $y \neq \theta y$ and $z \neq \theta z$.

Let P_α, for $\alpha = x, y, z, \theta x, \theta y, \theta z$, be the direction dependent propositions,

(P_α) the square of the spin in the direction $\alpha = 0$,

and consider two ideal measurement procedures, one associated with the triple of directions, x, y, z, and the other with the triple of directions, $\theta x, \theta y, \theta z$.

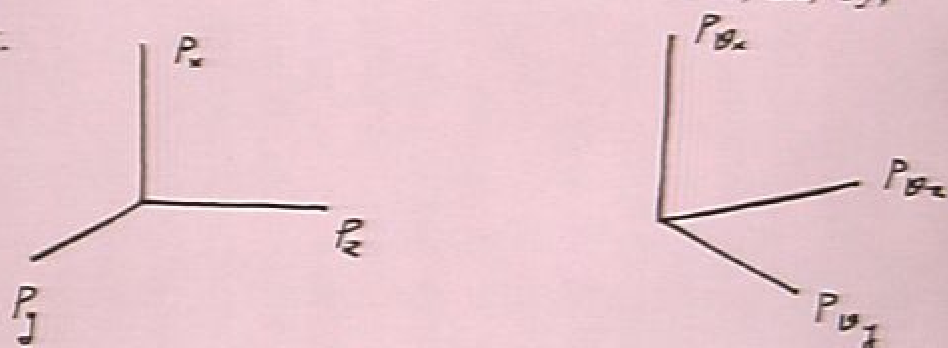

Figure 2

Two families of direction-dependent propositions

Contextuality concerns whether it is justifiable to regard the propositions P_x and $P_{\theta x}$ as the same proposition given the difference in the operational procedures by which they are measured: one measures P_x in conjunction with P_y and P_z; the other measurement occurs in the context of a measurement of $P_{\theta y}$ and $P_{\theta z}$.

The statistical states of QM are such that for any ρ, $p_\rho(P_x) = p_\rho(P_{\theta x})$, so that the probability assignments of quantum mechanics are non-contextual in the sense that they do not distinguish P_x on the basis of the context in which it is measured.

The significance of the possibility of contextual hidden variable theories centers on whether it is justifiable to require that the two-valued measures of such theories should be non-contextual in the way in which those associated with the quantum mechanical states are non-contextual.

4. The desiderata are not satisfiable by propositions belonging to particles.

Kochen-Specker shows that the desiderata of determinacy and objectivity can be in tension with one another: relativity to the measurement context secures the determinacy of propositions belonging to particles, but only at the price of the objectivity of their constituent properties.

That the same property may be presented differently, as the property indicated by a number of different measurement procedures, and that counterfactual reasoning in association with a multiplicity of measurement procedures is legitimate, are indispensable to our concept of the objectivity of physical properties.

Hence, a great deal of what supports the objectivity of physical properties is rendered vacuous when, as in a contextualist hidden-variable theory, properties are bi-uniquely paired with operational procedures.

Thus a hidden variable theory which is contextualist, cannot be a natural interpretation, since in order to maintain the determinacy of propositions belonging to particles it must give up the objectivity of a system's dynamical properties; as a result, such an interpretation must reject the idea that the concept of reality appropriate to particles is observer independent.

5. The satisfaction of observer independence by the framework of effects.

The *basic notion* for preserving observer-independence as a desideratum is that of an *effect*.

Effects are the traces of particle interactions on systems which are classical in the sense that their description is unproblematically *propositional*, i.e. effects are traces left on systems whose associated propositions form a Boolean algebra. *This is the sense in which such systems are epistemically accessible to us*.

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The problem of hidden variables arises when such traces are taken to be indicative of a particle's dynamical properties.

The objectivity of properties then requires that had a different effect been elicited, it would have revealed that the particle possessed a different property.

Proceeding in this way, we are led to a contradiction with the observation that for every orthogonal triple of directions x, y, z, exactly one of the propositions P_α is true for $\alpha = x, y, z$.

But if the conceptual framework is one according to which the theory speaks only of effects and non-dynamical properties, the problems of determinacy and objectivity for dynamical properties are completely avoided.

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They are avoided without invoking the idea that our concept of reality has to be replaced by one that is observer-dependent.

What is given up is a theoretical commitment to describing a particle's dynamical properties.

Particles give rise to the effects they do, and have a "being thus" in Einstein's phrase, that is entirely consonant with our classical concept of reality.

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But the transition from a propositional framework to an effects framework means replacing the characterization of a particle by a list of its dynamical properties with one according to which a particle's characterization has the form of a function:

When presented with an experimental idealization of some naturally occurring situation, particles are characterized not by changes in their dynamical properties, but by the effects they produce.

The fact that these effects cannot be anticipated with certainty—in the strong sense in which this is exhibited by the Kochen-Specker theorem—is interpreted within the effects framework as a manifestation of indeterminism, and it is so interpretable without any appeal to the failure of determinacy or objectivity.

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