Experimental Refutation of a Class of Models of the Elementary Process Theory as Underlying Standard Quantum Mechanics

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Abstract—In the context of the research program aimed at proving that the Elementary Process Theory (EPT) satisfies the correspondence principle, we have investigated the possibility that Standard Quantum Mechanics (SQM) emerges from a model of the EPT, in which the vectorial property 'spin' is a secondary property in Lockean sense and states of being of rest-mass-having entities like electrons, protons, and neutrons carry a constant scalar property η with value $+1$ or -1, such that measurements of the spin component in any direction yield the value $\eta/2$. The result is negative, since Barkan *et al.* (Rev. Sci. Instrum. 39(1), 101-104, 1968) have reported that a polarized neutron beam again splits up in a Stern-Gerlach apparatus after depolarization: this cannot possibly be explained by the above assumption of a constant scalar property. The conclusion is therefore that it is not possible that SQM emerges from any such model of the EPT, in which it is assumed (in addition to the axioms of the EPT) that the fundamental rest-mass-having components carry a constant scalar property but no vectorial property spin. This result can be generalized to all deterministic hidden-variable theories that include this assumption.

keywords: foundations of physics, spin, hidden variable theories

The Elementary Process Theory (EPT) has been introduced as a formalized axiomatic system that can potentially be applied as a foundational framework for physics under the condition that the gravitational interaction between matter and antimatter is repulsive [1, 2, 3]. The two main issues are (i) that it is unknown whether or not the physical world satisfies this condition of repulsive gravity, and (ii) that there is no proof that the EPT satisfies the correspondence principle. Resolving the first issue requires a technically very difficult experiment; there are a number of projects ongoing or in the works, see e.g. [4, 5, 6, 7, 8], but the most optimistic estimate for the time when definite results are known is 2015/2016[1]. Resolving the second issue is a theoretical challenge: using the formal theory/model distinction [9], the idea is to construct a model of the EPT, such that this model yields (approximately) the same predictions as relativity and quantum theory in their proven area of application. This is the context for the present investigation.

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[1]M. Doser, CERN, personal communication (2013).

Given that the EPT describes a universe at such a level of abstractness that its indivisible building blocks—called *phase quanta*—have no quantitative properties, a question is then whether Standard Quantum Mechanics can emerge from a deterministic model M^* of the EPT, in which it is assumed in addition to the axioms of the EPT

(i) that 'spin' is a *secondary property* in the sense meant by Locke[2];

(ii) that states of being of rest-mass-having entities like electrons, positrons, (anti)protons, (anti)neutrons, etc. are endowed with a constant scalar property η with value $+1$ or -1, but not with spin;

(iii) that a measurement of the $x-, y-$ or $z-$component of the particle's spin then always yields the value $\frac{\eta\hbar}{2}$.

In other words, it is assumed that a spin measurement in any direction (x, y, or z) on a particle with $\eta = +1$ will always yield the value 'spin-up', and a spin measurement in any direction on a particle with $\eta = -1$ will then always yield the value 'spin-down'. Thus speaking, the research question here is whether observed effects that are usually attributed to the *vectorial* property 'spin' might also be explainable with a constant *scalar* property η.

While we can imagine that it might be possible to explain the splitting of the neutron beam in simple Stern-Gerlach experiments as reported in [10, 11] with a constant scalar property, it becomes more interesting when a polarized particle beam—that is, a beam of particles that all have the same value of the property 'spin'—is being experimented with. The point is, namely, that a model M^* of the EPT satisfying the conditions (i)-(iii) above predicts that such a beam cannot be manipulated to again split up in a Stern-Gerlach apparatus: the idea is that the value of the constant property η cannot be changed, so if the particles all have the property $\eta = +1$, then the entire beam will be deflected to the position on the detection screen that corresponds with 'spin up'—*regardless of the orientation of the magnetic field*!

A literature search then yields the 1968 paper by Barkan *et al.* [12], in which an experiment is described on neutrons that successively run through a polarizer, a depolarizer, and a Stern-Gerlach apparatus with the magnetic field in the same direction as the direction of polarization. Summarizing, the results are the following:

(a) without the depolarizer, the polarized neutron beam is deflected to one side in the Stern-Gerlach apparatus;

(b) with the polarizer inserted, the neutron beam splits up in the Stern-Gerlach apparatus.

This unambiguously demonstrates that a polarized neutron beam after depolarization again splits up in a Stern-Gerlach apparatus. The model M^* of the EPT is thus inconsistent with this result, for if the polarized neutrons would all have the constant scalar property $\eta = +1$ then inserting the depolarizer would have no effect: it would then not have been possible to manipulate the beam so that it splits up in the Stern-Gerlach set up—in other words: in (b) above, the result would have been that (with the depolarizer inserted) the beam would still deflect to just one side of the Stern-Gerlach apparatus.

Standard QM, on the other hand, predicts that a beam of polarized neutrons in the eigenstate $|\ s_z\!\uparrow\ \rangle$ will split up in a Stern-Gerlach apparatus with the magnetic field in $y-$direction, as it predicts that the probability $\Pr^{|\ s_z\uparrow\ \rangle}(s_y\!\uparrow)$ that a measurement of the $y-$component of spin on a neutron in the eigenstate $|\ s_z\!\uparrow\ \rangle$ yields the outcome $s_y\!\uparrow = \frac{\hbar}{2}$ is 50%, which is identical to the probability $\Pr^{|\ s_z\uparrow\ \rangle}(s_y\!\downarrow)$ that it yields the outcome $s_y\!\downarrow = -\frac{\hbar}{2}$:

$$\Pr^{|\ s_z\uparrow\ \rangle}(s_y\!\uparrow) = |\langle\ s_z\!\uparrow\ |\ s_y\!\uparrow\ \rangle|^2 = \Pr^{|\ s_z\uparrow\ \rangle}(s_y\!\downarrow) = |\langle\ s_z\!\uparrow\ \rangle|\ s_y\!\downarrow\ \rangle|^2 = 0.5 \tag{1}$$

[2]That is, a property that is observable but that is **not** present in the thing in itself (like color).

Although it has apparently never explicitly been tested with particles as elementary as neutrons whether a beam of polarized particles again splits up in a Stern-Gerlach apparatus with its magnetic field perpendicular both to the direction of the beam and to the direction of polarization, on the basis of the results by Barkan *et al.* there is no doubt at all that the predictions of QM will obtain. In other words, on the basis of the results by Barkan *et al.* we can consider equation (1) an experimentally confirmed prediction of Standard QM.

The inevitable conclusion is then that Standard QM cannot possibly emerge from a model M^* of the EPT that satisfies the conditions (i)-(iii) above: experimental data obtained from observations on neutrons that can be explained with the vectorial property 'spin' in Standard QM cannot be explained with a constant scalar property η. The assumption that states of non-zero rest mass entities such as electrons, protons, neutrons, and their antimatter counterparts, are endowed with such a constant scalar property η is thus not a valid route towards a proof that the EPT satisfies the principle of correspondence.

As the empirical invalidity of the model M^* is not due to the axioms of the EPT, this result can be generalized to any deterministic hidden-variable theory that satisfies the conditions (i)-(iii) above, that is, that aims to explain observations attributed to the vectorial property 'spin' with a constant scalar property η (which is the hidden variable). No such theory can underly Standard QM or correspond with physical reality.

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