A Theory of Quantum Preparation and the Corresponding Advantage of the Relative-Collapse Interpretation of Quantum Mechanics as Compared to the Conventional One

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Analyzing two standard preparators, the Stern-Gerlach and the hole-in-the-screen ones, it is demonstrated that four entities are the basic ingredients of the theory: the composite-system preparator-plus-object state (coming about as a result of a suitable interaction between the subsystems), a suitable preparator observable, one of its characteristic projectors called the triggering event, and, finally, the conditional object state corresponding to the occurrence of the triggering event. The concepts of a conditional state and of retrospective apparent ideal occurrence are discussed in the conventional interpretation of quantum mechanics. In the general theory of a preparator in this interpretation first-kind and second-kind preparators are distinguished. They are described by the same entities in the same way, but in terms of different physical mechanisms. In this article the relative-collapse interpretation is extended to encompass also preparators (besides measuring apparatuses). In this interpretation also the mechanisms become the same and one has only one kind of preparators.

Key words: quantum preparators, interpretations, measurement.

1. INTRODUCTION

In Sections 2-6 we discuss a theory of quantum preparators in the context of usual quantum mechanics. In Section 7 we enter the relative-collapse interpretation of quantum mechanics and show that the expounded preparator theory is simpler and more natural in this interpretation.

We start by constructing a preparator out of a measuring device. The
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most elementary of the latter is the Stern-Gerlach (S-G) spin-projection measuring instrument described in almost every textbook on quantum mechanics.

2. STERN-GERLACH PREPARATORS

To begin with, let us sum up some of the familiar features of the S-G measuring instrument in order to single out the relevant ones important both in the conventional and in the relative-collapse interpretations of quantum mechanics.

We assume that it is the z-projection of the spin that is measured. As well known, the magnetic field couples the spatial degrees of freedom of the outgoing particle (leaving the field and approaching the plates) with its z-projection of spin as follows:

\[ |\Phi\rangle_{12} \equiv \alpha |\psi^+\rangle_1 (+, z)_2 + \beta |\psi^-\rangle_1 (-, z)_2 \]  

if the incoming particle was in the uncorrelated pure state given by the state vector

\[ |\Psi\rangle_{12} \equiv |\psi^0\rangle_1 (\alpha |+\rangle_2 + \beta |\rangle_2). \]

Here \( \alpha, \beta \in \mathbb{C}, \ |\alpha|^2 + |\beta|^2 = 1; \) the first subsystem consists of the spatial degrees of freedom of the particle, and the second one is that of spin; \( |\psi^+\rangle_1, |\psi^-\rangle_1, \) and \( |\psi^0\rangle_1 \) are the outgoing upward moving, the outgoing downward moving and the incoming spatial state vectors respectively; and, finally, \( |\pm, z\rangle_2 \) are the spin-up and spin-down (along z) state vectors respectively.

Let us introduce the projectors

\[ P^+_1 \equiv \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \int_{0}^{+\infty} |x, y, z\rangle_1 \langle x, y, z|_1 dx dy dz, \quad (2a) \]

\[ P^-_1 \equiv \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \int_{-\infty}^{0} |x, y, z\rangle_1 \langle x, y, z|_1 dx dy dz \quad (2b) \]

projecting onto the upper and the lower halfspace respectively. We define

\[ A_1 \equiv a_+ P^+_1 + a_- P^-_1 \]  

with arbitrary but fixed \( a_+ \neq a_-, \quad a_+, a_- \in \mathbb{R}. \)

Thus we have obtained the four basic entities for our theory of the preparator (in both interpretations):

\[ |\Phi\rangle_{12}, \quad A_1, \quad P^{(\bar{n})}_1 \equiv P^+_1, \quad \rho^{(\bar{n})}_2 \equiv |+, z\rangle_2 \langle +, z|_2, \quad (4a, b, c, d) \]
where "\( \bar{n} \)" is the quantum number fixing a particular characteristic event (projector) out of those appearing in the spectral form (3). We call the singled-out event the *triggering event* of preparation, and we take into account that

\[
P_{1}^{+} |\psi^{+}\rangle_{1} = |\psi^{+}\rangle_{1}, \quad P_{1}^{+} |\psi^{-}\rangle_{1} = 0.
\]

Hence, the ideal occurrence of the first-subsystem event \((P_{1}^{+} \otimes 1)\) in the composite-system state \(|\Phi\rangle_{12}\) brings the second subsystem into the state \(|+,-,z\rangle_{2}\). (According to the Lüders formula \(^{1}\) - cf also Messiah \(^{2}\) - one applies the projector onto the state vector and one renormalizes the result.)

It is noteworthy that the composite-system state (4a) and the first-subsystem observable (4b) with a purely discrete spectrum are completely independent of each other. The particular characteristic projector (4c) is very much related to the mentioned observable, and the second-subsystem state (4d) is related to the mentioned projector as the state which comes about when the event represented by the projector occurs in the composite system state (4a). (More about this in Section 4.)

The S-G measuring apparatus performs nonrepeatable or second-kind measurement in its standard form (when the particles are stopped on the plates). Therefore, to obtain a preparator, some modification is required.

2.1. *The First Modification for a S-G Preparator*

We assume that the S-G device is modified so that the upper plate is removed, and in its place we have a detector that detects the presence of the particle, but so that

(i) the particle is not stopped; it leaves the device, and

(ii) the detector does not interact with the particle by electromagnetic interaction.

Evidently, requirement (i) is necessary to have a first-kind (or repeatable) measurement, the only kind that may amount to a preparation. Requirement (ii) is indispensable because we need a measurement of the first-subsystem observable \(A_{1}\), i.e., of \((A_{1} \otimes 1)\), in the state \(|\Phi\rangle_{12}\) (to avoid a spin flip on the particle due to the absorption of a photon).
Once the particle has left the magnetic field of the S-G device, there is nothing to couple the spatial and the spin degrees of freedom (the two subsystems do not interact) in the time interval \( t_i \leq t \leq t_f \). Here \( t_i \) is the instant when the interaction in the (1+2)-system ends, the state \(|\Phi\rangle_{12}\) is established, and the (instantaneous) triggering event occurs in \(|\phi_{12}\rangle\). At \( t_i \) the preparation is completed. It is the initial moment of the quantum experiment. We denote by \( t_f \) the subsequent instant when an (instantaneous) measurement on the second subsystem is performed and the final moment of the experiment is thus reached.

It is important to note that there is (at least in a sufficiently good approximation) no interaction between subsystems 1 and 2 in this time interval. Besides, in good approximation, our composite system is isolated.

We have described a preparator in a thought experiment. It might be real hard to construct a laboratory detector that does not interact electromagnetically. This gives sufficient motivation to discuss another modification of the standard S-G measuring apparatus.

### 2.2. The Second Modification for a S-G Preparator

The upper plate is removed again, but it is not replaced by anything. The particle that would hit the upper plate in the standard S-G instrument may now fly out freely. The lower plate is also removed, and it is replaced by a particle detector that may be as realistic as one wishes.

We want a so-called negative measurement: it consists in the anticoincidence of arrival of the particle on the plates and of nondetection in the place of the lower plate. This amounts to ideal occurrence of \( P^{(\bar{n})} = P^+_1 \), which is our triggering event.

The described anticoincidence is hard to achieve in the laboratory because it is not easy to make certain when the particle is supposed to arrive at the plates. There is motivation for a third modification.

### 2.3. The Third Modification for a S-G Preparator

We remove the upper plate, but we do not care about the lower plate. We have a geometry that makes it possible to make us interested only in the upper halfspace, where we put our measuring apparatus. If it measures anything on the particle (at \( t_f \)) and one obtains a result, then, due to
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the geometry, the particle must be in the upper halfspace. Therefore, it must be in the state

\[ (U_1(t_f - t_i, t_i)|\psi^+\rangle_1)|+, z\rangle_2, \]

where "\(U_1(...)\)" is a purely spatial evolution operator (the spin does not change). This amounts to the same as if we had occurrence of the triggering event \((P_1^+ \otimes 1)\) at \(t_i\) in the state \(|\Phi\rangle_{12}\) (and subsequent evolution).

To check if we are dealing with sufficiently general basic concepts of preparation in standard quantum mechanics, let us take another, a quite different and very well known example.

3. PREPARATION THROUGH A HOLE

Letting a beam through two successive holes in two parallel screens, the preparation of a rather concentrated (e.g. pencil-shaped) beam is achieved. This procedure consists of two equal stages. We start by describing just one of them with the purpose to show that it fits into the theoretical scheme suggested by the preceding examples of preparation.

In one-hole preparation the first subsystem is the screen, the second is the particle. Let the screen be in the pure state \(|\psi, t_i - \epsilon\rangle_2\) immediately before the initial moment of the experiment \((0 < \epsilon \ll 1)\). We think of the screen as of an infinite surface perpendicular to the motion of the incoming particle. Let the latter be in the pure state \(|\chi, t_i - \epsilon\rangle_2\).

The screen is thought of as in some way broken up into nonoverlapping segments (the slit is one of them) enumerated by "n" ("\(\bar{n}\)" refers to the slit). Hitting the \(n\)-th segment, i.e., transfer of linear momentum at this segment, corresponds to the occurrence of the projector \(P_1^{(n)}\). These (orthogonal) projectors are assumed to add up as follows:

\[ \sum_n P_1^{(n)} = P_1, \]  \hspace{1cm} (5)

and occurrence of the complementary projector \(P_1^{\perp} \equiv (1 - P_1)\) has the physical meaning that the screen is not hit at all (the particle has not reached it yet).

Correspondingly, the occurrence of the particle event (projector) \(Q_2^{(n)}\) means that the particle has hit the \(n\)-th segment at \(t_i\). Again
\[ \sum_n Q_2^{(n)} \equiv Q_2, \text{ and } Q_2^\perp \text{ corresponds to the event that the particle has not reached the screen yet. The composite-system state vector is} \]

\[ |\Phi, t_i\rangle_{12} = \sum_n [(P_1^{(n)}|\psi, t_i\rangle_1)(Q_2^{(n)}|\chi, t_i\rangle_2)] + (P_1^\perp|\psi, t_i\rangle_1)(Q_2^\perp|\chi, t_i\rangle_2) \quad (6) \]

in full analogy with relation (1) for the S-G device. Here we have, of course, assumed that the events occur in an ideal way, i.e., that the Lüders state-projection formulae can be applied. This is an oversimplification. (It will be improved upon below.)

The second crucial entity for the theory of preparation is an observable \( A_1 \) with the spectral form

\[ A_1 \equiv \sum_n a_n P_1^{(n)} + a_\perp P_1^\perp, \quad (7) \]

where all characteristic values are distinct (otherwise arbitrary but fixed). The triggering event \( P_1^{(\bar{n})} \) corresponds to the hole, and, finally, the state of the particle at the final moment of preparation is \( cQ_2^{(\bar{n})}|\chi, t_i\rangle \), where "c" is a normalization constant.

In a more realistic theory, the correlated composite-system state is still a pure one, given by a state vector that we decompose as follows

\[ |\Phi, t_i\rangle_{12} \equiv (P_1^\perp \otimes 1)|\Phi, t_i\rangle_{12} + \sum_n (P_1^{(n)} \otimes 1)|\Phi, t_i\rangle_{12}. \quad (8) \]

The second and third basic entities (i.e., \( A_1 \) and \( P_1^{(\bar{n})} \)) are unchanged, but the fourth, the state of the particle when the preparation is completed, is (as known but not widely known):

\[ \rho_2^{(\bar{n})}(t_i) \equiv Tr_1[(c(P_1^{(\bar{n})} \otimes 1)|\Phi, t_i\rangle_{12})(\langle \Phi, t_i|_{12}(P_1^{(\bar{n})} \otimes 1)c)], \quad (9) \]

where "c" is a normalization constant, and "\( Tr_1 \)" denotes the partial trace over subsystem 1. (It is, of course, assumed that \( (P_1^{(\bar{n})} \otimes 1)|\Phi, t_i\rangle_{12} \neq 0 \), i.e., that the process considered allows passage through the hole with positive probability.)

The state \( \rho_2^{(\bar{n})} \) is determined by the composite-system state and the triggering event in the same way as in the case of the S-G device (cf (4d) and (1)) or the oversimplified composite-system state vector (6) for the one-hole preparation. (We discuss in detail this partial-trace evaluation below in Section 4.)
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If one has two successive holes, as one usually does in the laboratory, then, denoting by $t'_i$ and $t_i$ the instants of possible passage of the particle through the first and the second hole respectively ($t'_i < t_i$), the incoming state of the particle in relation to the second hole is then

$$U_2(t_i - t'_i, t'_i) \rho_2^\left(i\bar{n}\right)(t'_i) U_2^\dagger(t_i - t'_i, t'_i),$$

where $U_2$ is the evolution operator of the motion of the particle between the two screens, and $\rho_2^\left(i\bar{n}\right)(t'_i)$ is the state of the particle at $t'_i$. Then the described theory is (essentially) repeated (in terms of mixed states).

In analogy with our above described modifications of the S-G device, we can think of modifications of the hole-preparator.

The first one goes as follows.

It is conceivable, in a thought experiment, to put a detector into the very hole. It should let the particles through without changing their state and give information on the event of passage.

Naturally, passage results in the particle state $\rho_2^\left(i\bar{n}\right)(t_i)$ given by (9).

The second modification is achieved in the following way.

We can imagine (in a thought experiment) all segments of the screen being actually detectors except the hole itself. The occurrence of the triggering event $P_1^\left(i\bar{n}\right)$ amounts then to the anticoincidence of the arrival of the particle to the screen (nonoccurrence of $P_1^\perp$) and nonoccurrence of all the events $\{P_1^n : n \neq \bar{n}\}$. The prepared state of the particle is again given by (9).

The third modification is, actually, the original arrangement, when the state given by (9) is a conditional one. It is valid if the particle passes the hole (but we do not know that this or the opposite event occurs). Here the geometry is trivially such that if anything is measured on the particle to the right of the screen at $t_f$, the former must have passed the hole, i.e., it is as if the triggering event had occurred at $t_i$. (This will be discussed in detail in Section 5.)

We have now sufficient inductive insight for a general standard quantum mechanical theory of preparation. Nevertheless, it is desirable to discuss further two points.

(i) As it was stated, the conditional state expressed by the partial-trace formula (9) is known. But since it is not only essential for preparation, but also for a further development of the relative-collapse interpretation, we present its derivation in the next section.
(ii) The precise meaning of the words ”as if the triggering event occurred at \( t_i \)” in the case of \( \rho_2^{(n)} \) being a conditional state (the third modification) must be explained in more detail (in Section 5), the more so since it is based on a recent result of the author.

4. WHY THE PARTIAL-TRACE EVALUATION?

Let \( \rho_{12} \) be an arbitrary given composite-system (mixed or pure) state (a statistical operator). Let, further, \( P_1 \) be a first-subsystem event (projector) and let it occur in whatever way in the state \( \rho_{12} \). We want an answer to the question: In what state leaves this occurrence the second subsystem?

The sought-for state (statistical operator) \( \rho_2 \) gives probability prediction for an arbitrary second-subsystem event (projector) \( Q_2 \) through the formula \( Tr_2(\rho_2Q_2) \), and, as well-known, \( \rho_2 \) is thus determined by the totality of all possible \( Q_2 \).

Since \( P_1 \) and \( Q_2 \) are compatible events (commuting projectors), their coincidence on the one hand and the occurrence of \( Q_2 \) immediately after that of \( P_1 \) on the other is one and the same thing. The coincidence probability can, as easily seen, be written in a factorized form

\[
Tr_{12}[\rho_{12}(P_1 \otimes Q_2)] = [Tr_1(\rho_1P_1)][Tr_2(\rho_2Q_2)],
\]

where \( \rho_1 \) is the state (reduced statistical operator) of the first subsystem, \( \rho_1 = Tr_2\rho_{12} \). The first factor on the RHS is the probability of the event \( P_1 \) in \( \rho_{12} \), and, finally, \( \rho_2 \) is given by

\[
\rho_2 \equiv [Tr_1(\rho_1P_1)]^{-1}Tr_1[\rho_{12}(P_1 \otimes 1)].
\]

Coincidence can be thought of as taking place in one measurement, hence (10) can be viewed classically, and, the second factor on the RHS of (10) is then, by definition, the conditional probability of \( Q_2 \) in the state in which the second subsystem is left (immediately) after the occurrence of \( P_1 \) in \( \rho_{12} \). Since \( \rho_2 \) defined by (11) is a statistical operator, as easily seen, and since \( Q_2 \) is an arbitrary event, \( \rho_2 \) actually describes the mentioned state. Hence, it is the sought-for expression justifying our partial-trace evaluation in (9).
5. THE CONDITIONAL STATE AND RETROACTIVE APPARENT IDEAL OCCURRENCE

When there is no detector in the preparator, i.e., when it is no measurement at all (the third modification in our discussions above), then the most important of the four entities, the state $\rho_2^{(\bar{n})}(t_i)$ given by (9), has the meaning of a conditional state, assuming validity under the condition that the triggering event $(P_1^{(\bar{n})} \otimes 1)$ occurs in the composite-system state $\rho_{12}$ at $t_i$.

There is no actual occurrence of any event until $t_f$, when a measurement result is obtained. Then, owing to the geometry of the experiment, this amounts to the same, as it was claimed above, as if $(P_1^{(\bar{n})} \otimes 1)$ had occurred in $\rho_{12}$. This requires additional explanation.

If any measurement result is obtained on the particle at $t_f$, this takes place in a certain spatial region $V$ (e.g. to the right of the screen if the particle approaches the screen before $t_i$ from the left). Hence, the mentioned result coincides with the occurrence of the event $Q_2(V)$ by which we mean that the particle is in the mentioned region $V$.

If the triggering event $(P_1^{(\bar{n})} \otimes 1)$ occurs in $\rho_{12}(t_i)$ (i.e., if the screen undergoes the change - linear-momentum transfer - corresponding to the particle’s passage through the hole), then at $t_f$ the event $Q_2(V)$ is certain to occur in the state $U_{12}\rho_{12}(t_i)U_{12}^\dagger$, where $U_{12}$ (≡ $U_{12}(t_f - t_i, t_i)$) is the evolution operator of the composite system describing its evolution from $t_i$ till $t_f$. This means that the particle must reach the region $V$. Moreover, if the triggering event does not occur, i.e., if the opposite event $[1 - (P_1^{(\bar{n})} \otimes 1)]$ occurs, at $t_i$ in $\rho_{12}$, then $Q_2(V)$ will not occur, i.e., $[1 - Q_2(V)]$ will occur, at $t_f$ in the state $U_{12}\rho_{12}(t_i)U_{12}^\dagger$.

There is a theorem(3) that says that on account of the two mentioned implications one must have

$$\left[(1 \otimes Q_2)[U_{12}\rho_{12}(t_i)U_{12}^\dagger](1 \otimes Q_2)\right]/Tr_{12}\{(1 \otimes Q_2)[U_{12}\rho_{12}(t_i)U_{12}^\dagger]\} =$$

$$U_{12}\{(P_1^{(\bar{n})} \otimes 1)\rho_{12}(t_i)(P_1^{(\bar{n})} \otimes 1)\}/Tr_{12}\{(P_1^{(\bar{n})} \otimes 1)\rho_{12}(t_i)\}\}U_{12}^\dagger, \quad (12)$$

This means that one has the same state if, on the one hand, the event $(1 \otimes Q_2)$ occurs ideally at $t_f$ in the state $[U_{12}\rho_{12}(t_i)U_{12}^\dagger]$, and, on the other hand, if the triggering event $(P_1^{(\bar{n})} \otimes 1)$ occurs ideally at $t_i$ in the state $\rho_{12}(t_i)$ and then the system evolves till $t_f$. 
If one utilizes the RHS of (12) instead of its LHS (for the composite-system state at $t_f$), then one says that one has \textit{retroactive apparent ideal occurrence} (RAIO) of the event $(P_1^{(\bar{n})} \otimes 1)$ in $\rho_{12}(t_i)$ at $t_i$ as a consequence of the \textit{actual occurrence} of the event $(1 \otimes Q_2)$ in $U_{12}\rho_{12}(t_i)U_{12}^\dagger$ at $t_f$.

Returning to our investigation, we consider the RAIO of $(P_1^{(\bar{n})} \otimes 1)$ in $\rho_{12}(t_i)$. We are actually not interested in the composite-system state, but in the state of the second subsystem, i.e., of the particle. It is in the state described by the reduced statistical operator:

$$Tr_1[(P_1^{(\bar{n})} \otimes 1)\rho_{12}(t_i)(P_1^{(\bar{n})} \otimes 1)]/Tr_{12}[(P_1^{(\bar{n})} \otimes 1)\rho_{12}(t_i)],$$

which equals $\rho_2^{(\bar{n})}(t_i)$ given by (9) if one puts

$$\rho_{12}(t_i) \equiv |\Phi, t_i\rangle\langle \Phi, t_i|.$$

Utilizing the identity

$$1 = (P_1^{(\bar{n})} \otimes 1) + (P_1^{(\bar{n})\perp} \otimes 1),$$

we can write

$$U_{12}|\Phi, t_i\rangle = U_{12}[(P_1^{(\bar{n})} \otimes 1) + (P_1^{(\bar{n})\perp} \otimes 1)]|\Phi, t_i\rangle_{12}.$$

Further, since the screen and the particle do not interact any longer if the latter has passed the hole, the evolution operator $U_{12}$ factorizes tensorically into the evolution operator of the screen $U_1$ and that of the particle $U_2$ in this case (analogously as in Subsection 2.3). More precisely,

$$U_{12}(P_1^{(\bar{n})} \otimes 1) = (U_1 \otimes U_2)(P_1^{(\bar{n})} \otimes 1),$$  
(13)

and, owing to this, we can derive a simple form of the state of the particle at $t_f$ in the region $V$ (relation (14) below).

Some event (corresponding to the measurement result) is going to occur in the region $V$. Since the measurement apparatus is in $V$, the occurrence of this event implies the occurrence of the event $Q_2(V)$. Naturally, the measured event and $Q_2(V)$ are compatible. We may imagine that it is $Q_2(V)$ that occurs first, and the other event occurs immediately afterwards. Since $Q_2(V)$ is not actually measured (only implied), we are justified to assume that its occurrence takes place in the ideal way. Hence, we take the LHS of (12) as the relevant composite-system state, and we replace it by the RHS of (12). Then we obtain:
\[ \rho_2^{(\bar{n})}(t_f) = \]

\[ Tr_1\{U_{12}[{(P_1^{(\bar{n})} \otimes 1)} \rho_{12}(t_i) {(P_1^{(\bar{n})} \otimes 1)}]/Tr_{12}((P_1^{(\bar{n})} \otimes 1) \rho_{12}(t_i))]U_{12}^\dagger}\].

Replacing here (13), we can take \( U_2 \) and \( U_2^\dagger \) outside the partial trace and we can omit \( U_1 \) and \( U_1^\dagger \) under the partial trace. (These are known partial-trace identities.) We finally obtain:

\[ \rho_2^{(\bar{n})}(t_f) = U_2 \rho_2^{(\bar{n})}(t_i) U_2^\dagger, \quad (14) \]

\[ \rho_2^{(\bar{n})}(t_i) \equiv Tr_1[{(P_1^{(\bar{n})} \otimes 1)} \rho_{12}(t_i) {(P_1^{(\bar{n})} \otimes 1)}]/Tr_{12}((P_1^{(\bar{n})} \otimes 1) \rho_{12}(t_i))]\]. \quad (15)

It is perhaps worth noticing that also the event \( (1 \otimes Q_2^{(\bar{n})}) \) of the very passage of the particle through the hole at \( t_i \) may play a role in the theory. Actually, it stands in the same relation to \( (1 \otimes Q_2(V)) \) as \( (P_1^{(\bar{n})} \otimes 1) \) does (cf the above mentioned theorem and (12)). Moreover, it stands in this same relation also to the latter event because \( (1 \otimes Q_2^{(\bar{n})}) \) occurs if and only if \( (P_1^{(\bar{n})} \otimes 1) \) does. This makes these two events twin\(^{(3)}\) events in the composite-system state \( \rho_{12}(t_i) \). This means that the two events have also the same probability in this state, and that their ideal occurrence changes the state equally.

6. GENERAL THEORY OF THE QUANTUM PREPARATOR IN THE CONVENTIONAL INTERPRETATION OF QUANTUM MECHANICS

Actually, both the S-G preparator and the hole preparator were presented in the conventional interpretation of quantum mechanics (QM). This is the text-book interpretation, actually a simplified form of the so-called Copenhagen one\(^{(4)}\).

We now outline the general theory, and subsequently we point out some unusual features in the conventional interpretation.

We call subsystem 2 the quantum object the state of which is going to be prepared. Subsystem 1 is the preparator. There are two instants \( t_i \) and \( t_f, \ t_i < t_f \). The former is the one when the preparation is completed and the experiment begins. The latter is the final moment of the experiment, when some observable is measured on subsystem 2.
The two subsystems interact and reach a composite-system state \( \rho_{12}(t_i) \). This is the first basic entity of the preparation. The second one is a first-subsystem observable \( A_1 \) with at least one discrete characteristic projector \( P_1(\vec{n}) \), which is called the triggering event, and which represents the third basic entity of preparation. The fourth basic entity is the conditional state \( \rho_{2}(\vec{n})(t_i) \) of the second subsystem to which the occurrence of the triggering event \( P_1(\vec{n}) \) in the state \( \rho_{12}(t_i) \) gives rise. (The occurrence may take place in whatever way, i.e., it need not be ideal). The conditional state is given by (15).

Finally, there is a fifth entity that belongs more to the experiment than to the preparation. It is the evolution operator

\[
U_{12} \equiv U_{12}(t_f - t_i, t_i)
\]

with the important property (13), which means noninteraction between object and preparator in the interval from \( t_i \) till \( t_f \) after the triggering event has happened (actually or retroactively apparently).

As a matter of fact, for a given preparator it is only \( U_2 \), the evolution operator of the object, that must be known (cf (14)). As to \( U_1 \), the evolution operator of the preparator, it is sufficient to know that it exists, and that it enters the theory via (13). The concrete form of \( U_1 \) is of no consequence.

In the conventional interpretation, we must distinguish two kinds of preparators: the immediate-occurrence or first-kind ones, in which the triggering event does actually occur at \( t_i \), and the delayed-occurrence or second-kind ones, in which a special geometry singles out a spatial region \( V \), and some event (corresponding to obtaining some measurement result on subsystem 2) actually occurs at the delayed moment \( t_f \). (It is delayed as far as the preparation, not the experiment, is concerned). But, as explained in detail in the preceding section, this gives rise to the retroactive apparent ideal occurrence (or RAIO) of the triggering event, and the entire theory has exactly the same form as for a first-kind preparator.

Now, I would like to point out some peculiar points in the theory in the conventional interpretation.

(i) We have one and the same formalism, but two different physical mechanisms, i.e., the two kinds of preparators are equally described, but we understand them as different processes.
(ii) The concept of RAIO, which enables us to describe both kinds of preparators by the same formalism, is a paradoxical one:

In our hole-in-the-screen example, intuitively we do feel that the particle must have passed the hole if it reaches region V. But QM seems to prove us wrong. Since there is no measurement at $t_i$, there is no collapse and no occurrence at that moment in actuality. The composite system is described by $U_{12}\rho_{12}(t_i)U_{12}^\dagger$ at $t_f$.

This state includes, possibly in a coherent (i.e., interference-allowing) way, also the possibility that the hole is not passed in the described example. At the final moment $t_f$, and only then, something happens, some measurement result is obtained. From the very fact that this result is obtained in the region V, we have the collapse described by the LHS of (12). It does imply the RAIO of the triggering event, but this is only formal (or apparent) if we take occurrence (collapse) really seriously (as we should in the conventional interpretation).

In the conventional interpretation of QM one does not search for the mechanism of the collapse, given rise to by the occurrence of some event. But, the collapse is taken very seriously: it is considered to be a real, objectively happening physical process.

At this point we have the basic branching of interpretations of QM: the conventional one with numerous foundational attempts to explain collapse with the help of one or another extra-quantum-mechanical agency, and the no-collapse approaches, which started with the theory of Everett$^{(5)}$. More will be said about them in the next section.

It is very important to realize that the collapse-a-real-process and the no-collapse interpretations experimentally contradict each other. Thus, only one of them is actually true. Unfortunately, the experiments required must find an observable incompatible with the pointer observable on the (classical) measuring apparatus (cf end of Section 6 in Ref. 6). This has not succeeded so far.

7. GENERAL THEORY OF THE QUANTUM PREPARATOR IN THE RELATIVE-COLLAPSE INTERPRETATION OF QUANTUM MECHANICS

As it was mentioned, the no-collapse approach to QM started with the famous article by Everett$^{(5)}$. Nowadays, it receives far less attention than the conventional approach. (Even its great initial admirer and, perhaps,
The Everett interpretation appears ambiguous to me: either it stipulates collapse as a real process (it is called falling into a branch of the universe), then it actually belongs to the collapse-a-real-process approaches, and is isomorphic to the conventional interpretation, or it does not. But then it is unclear how definite measurement results, on which every interpretation of QM hinges, come about.

To my mind, two elaborated and improved forms of the no-collapse approach are the modal\(^{(9)}\) and the relative-collapse\(^{(6)}\) interpretations. (See the discussion in Section 6 of Ref. 6.) I’ll utilize only the latter in relation to the theory of a quantum preparator.

The relative-collapse (RC) interpretation of QM takes the idea of no collapse seriously. There is no collapse either in first-kind or in second-kind preparation. Every measurement at \(t_f\) is performed in the composite system state \(\rho_{12}(t_f) = U_{12}\rho_{12}(t_i)U_{12}^\dagger\), which, in a possibly coherent way, contains both possibilities: the case when the preparation did succeed and that when it did not.

Nevertheless, the expounded quantum theory of a preparator has a very simple form in this approach. And it need not distinguish two kinds of preparators.

In the RC interpretation of QM it is important to have a well-defined subject. This is given in terms of a subsystem observable. The second basic entity \(A_1\) of the expounded formalism of the preparator suits this purpose perfectly.

One makes a shift of the cut (/) between subject (S) and object (O). In terms of the so-called splits (that, by definition, encompass besides the cut also the subject and the object), the shift is written as follows:

\[
S/O \equiv .../(1 + 2) \quad \rightarrow \quad S/O \equiv 1/2.
\]

This means that in the first split the object (of description) was the composite (1+2)-system, and one had an ill-defined subject. This was the case all the time so far. Then we join subsystem 1 (the preparator) to the subject. (Actually, the rest of the subject can be disregarded.) Only subsystem 2 remains the object.

For every individual system one characteristic event of \(A_1\), in general called the subject event, in this case it is the triggering event \(I_{1}^{(n)}\), constitutes the "zero point" of the "coordinate system" so to speak. The
object is described by the conditional state \( \rho_2^{(\bar{n})}(t_i) \) that is determined by
the condition that we take the triggering event as occurring. Finally, we
then we have the evolution into the state

\[
\rho_2(t_f) = U_2 \rho_2^{(\bar{n})}(t_i) U_2^\dagger.
\]

Since there is no occurrence (collapse) as a real physical process in
this approach, it is of no consequence if we have ”actual” or ”retroactive
apparent” occurrence of the triggering event at \( t_i \). It is anyway only our
optimal choice of subject, i.e., how to get rid of the irrelevant in \( \rho_{12}(t_i) \).

Just like in the theory of measurement\(^{(6)}\), in the theory of preparators
the RC interpretation of QM appears to be best adapted to the very
formalism of QM. The fact that makes it hard to accept is the idea that
no events are occurring. Instead, only the quantum correlations between
the subsystems are changing due to the interaction. The choice of a
split with a well-defined subject is only our subjective way of reading the
quantum correlations that are objectively there.

Thus, the interaction between preparator and object brings about the
objectively existing quantum correlations in \( \rho_{12}(t_i) \). The described choice
of subject brings out the relevant part, the object state \( \rho_2^{(\bar{n})}(t_i) \). And this
is precisely what is meant by preparation of the state of the object.

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