Quantum Postulates and Spacetime

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Abstract

We construct quantum postulates on a fundamental particles' level. For one, this leads to a clean version of postulates for generic *quantum systems*. And, secondly, suggested two-tier structure of quantum postulates naturally leads to viewing spacetime as an effective construction of relations between particle events.

1 Motivation

Quantum mechanics postulates talk about quantum systems, without specifying what those systems are. Yet, in this day and age, Standard Model (SM) pretty much tells us what sort of stuff is there in the world, and any "quantum system" must be constructed of fundamental particles from SM. This raises a question of whether initial quantum postulates better be postulated on a fundamental level of particles, and secondary postulates about compound quantum systems[1] can be derived from fundamental ones. So, in the following, we'll guess postulates on a fundamental level and deduce a set of postulates for use on the level of regular quantum mechanics. In the process we'll see, if this two-tier structure of postulates fixes interpretation of QM, and if it suggests directions to move beyond mere reformulation of QM.

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[1]An electron in Stern-Gerlach experiment, for example, is an effective electron, it is a cloud of many appearing and disappearing fundamental electrons that react with fundamental photons.

2 Postulates about fundamental particles

2.1 Matter Existence Postulate

There are many particles in Standard Model, and a list might be longer or shorter, but what is common, is that all these are particles, and these fundamental particles are created and annihilated at interaction events. This common theme we shall put into Matter Existence Postulate.

> **Postulate I:** There exist particles that are annihilated and created at interaction events. What sort of interaction events may or may not happen, what states of particles are required for interaction, and in what states particles are created, all of these aspects are dictated by a type of particles.

Notice that this is a postulate about matter existence, and, although we looked at Standard Model to form it, we in no way assume Minkowski or any other spacetime. There is no need to talk about spacetime now, but we'll sure do so later.

2.2 Probabilistic Nature of Particle Events

We know that events with fundamental particles occur all the time, but there seem to be no way to tell with certainty when a particular event will take place, which incoming particle will participate, and what will be an exact result of such event. Given such experience, and lacking any reasons as to why this must be true, let us state this behaviour explicitly in a postulate.

> **Postulate II:** Particle events are probabilistic. It is impossible to answer with certainty all following questions simultaneously: *a)* which event will occur, *b)* when and where relative to other events the said event will occur, and *c)* what will be the state of incoming and outgoing particles.

Notice that the following does not preclude us from using probabilities to forecast events.

Notice also that "what & where" of an event makes sense only relative to other events. This is how in practice GPS tells its position.

3 Postulates about effective objects (quantum systems)

First two postulates lay out fundamental rules for what and how things are in the world. But they are not really practical, cause most of our activities and technologies have to do with quantum systems that are effective objects spanning many fundamental particle events.

An electron in Stern-Gerlach experiment is an effective object. Firstly, some fundamental electron is created at a source of electrons. Secondly, it is annihilated at some event involving a photon, and a new electron, with different momenta is created. Then new electron is annihilated at another event, etc. But we look at all of this as one electron that interacts with a magnetic field, and takes a particular trajectory depending on its spin's orientation relative to that of a magnetic field.

A magnetic field in Stern-Gerlach experiment is also an effective object. It is a cloud of photons, that are created and annihilated in a multitude of fundamental particle events.

Postulates about these effective objects, or quantum systems, have to be in line with the particle postulates, simply because all quantum systems are made of fundamental particles.

3.1 Probabilistic Nature of Interaction

When we run Stern-Gerlach apparatus, we say that we measure spin of electrons. When asked how measurement is done, we say that electron interacts with a magnetic field, and changes its trajectory depending on its spin's direction, while a huge magnetic field takes a tiny hit of change in momenta. So, in essence, measurements are interactions, and we do not have to separate them into a different category.

Every interaction process consists of many fundamental particle events. According to postulate II, these are probabilistic. Therefore, in general, we can never be certain about interaction's outcome. And this inherent probabilistic nature of any interaction is a direct consequence of a probabilistic nature of particle events.

> **Postulate III:** When two systems ψ and ϕ interact with each other, they undergo a transition from some initial states $|\psi_{init}\rangle$

and $|\phi_{init}\rangle$ to final states $|\psi_j\rangle$ and $|\phi_j\rangle$, where only one of j possibilities may occur at a time with some probability:

$$|\psi_{init}\rangle, |\phi_{init}\rangle \longrightarrow \bigcup_j \left(|\psi_j\rangle, |\phi_j\rangle \quad with \quad P^{\psi}_{\psi_{init}\to\psi_j} = P^{\phi}_{\phi_{init}\to\phi_j} \right), \quad (1)$$

$$where \quad \sum_j P^{\psi}_{\psi_{init}\to\psi_j} = \sum_j P^{\phi}_{\phi_{init}\to\phi_j} = 1 \quad (2)$$

We will say that states $|\psi_j\rangle$ and $|\phi_j\rangle$ in each final pair are entangled with each other as a result of interaction.

3.2 Interaction Confinement

Postulate III tells us what happens when two systems ψ and ϕ interact. But the world does not consists of just two systems. Let's then ask, what will happen to the process (1), if we add some system Υ, that interacts with neither system ψ, nor system ϕ.

If nothing happens, then we will rewrite (1) as

$$|\Upsilon\rangle \left(|\psi_{init}\rangle, |\phi_{init}\rangle\right) \longrightarrow |\Upsilon\rangle \left(\bigcup_j \left(|\psi_j\rangle, |\phi_j\rangle \quad with \quad P_j\right) \right) \quad (3)$$

But what can possibly happen? Some philosophical considerations, based on everyday experience of a classical world, may lead one to suggest that a choice of final states in interaction of ψ and ϕ should be fixed to the rest of the world, even if it hasn't been communicated via actual interaction.

$$|\Upsilon\rangle \left(|\psi_{init}\rangle, |\phi_{init}\rangle\right) \longrightarrow \bigcup_j \left(|\Upsilon\rangle \left(|\psi_j\rangle, |\phi_j\rangle\right) \quad with \quad P_j\right) \quad (4)$$

In the case of (4), any unsuspecting system, like Υ, gets entangled with final states of interaction that happen between ψ and ϕ. Entanglement instantaneously spreads to the rest of the world, without any regard that a system like Υ may be light-years away from ψ and ϕ.

As nonlocal as option (4) sounds, the first option (3) may not be easy to swallow, either. It says that any choice of final states shall stay confined to interacting systems. A composite system (ψ, ϕ) does change its state as a result of internal interaction, but no entanglement choices "leak outside" when there is no interaction with the rest of the world, i.e. when (ψ, ϕ) is a closed system.

Can experimental evidence tell us which option nature itself prefers?

Let's recall a double-slit experiment, where electrons are thrown one by one at slits, with a subsequent interference pattern seen on the screen. An electron together with slits, or rather material in which slits are cut, form a composite system like (ψ, ϕ). Now, if (4) is correct, then a result of interaction with slits, through which electron passes, should be fixed to the rest of the world. Then a little electron counting, done at each slit, should make no difference, as it will only confirm an already fixed interaction outcome. But, according to an experiment, additional electron counting does make a difference. Therefore, option (4) is incorrect, and, by implication, option (3) is preferred by nature.

> **Postulate IV:** When interaction occurs between subsystems of a closed system, resulting entanglements between final states and choices thereof are confined to the system.[2]

4 Mathematical Clothing

Postulates III and IV are what is needed to have usual quantum mechanics. We only have to form some mathematical framework for use in particular calculations. Fortunately, we do not have to invent any new stuff.

Interaction processes of type (1) can be cast into operations with matrices. The sets of initial and final states can be identical, and transitions can be viewed as steps within one set of states. Some more sophistication will lead us to having inner product space, and all that will work over complex numbers, relating probability to a square of state's vector amplitude. It seems that Hilbert spaces can be constructed for any sort of interaction process.[3]

In (3) a composite system (ψ, ϕ) is "not loosing" any probability, as far as external system Υ is concerned. Therefore, when described using Hilbert spaces' language, a state vector that describes closed system (ψ, ϕ) should keep the same unit length as it goes through its evolution. In other words,

[2] Postulate IV can be expressed in almost obvious terms of information: Information transfer occurs only via physical interaction.

[3] If there is a problem, for which Hilbert space formalism is not working, we should simply construct another mathematical tool for dealing with it.

Postulate IV, when expressed using usual Hilbert spaces' language, says that evolution of a closed system is described by unitary transformations.

From a mathematics class we know that, given a hermitian operator $\hat{H}$ and a real number t, the following $\hat{U}$ operator is unitary:

$$\hat{U} = exp\left(-\frac{i}{\hbar}\hat{H}t\right) \tag{5}$$

and, therefore, it may describe a transformation of a state vector as a function of a numeric parameter t:

$$|\psi(t)\rangle = \hat{U}\,|\psi(0)\rangle$$

Taking a t derivative will do the following:

$$\begin{aligned}
\frac{\partial}{\partial t}|\psi(t)\rangle &= \frac{\partial}{\partial t}\hat{U}\,|\psi(0)\rangle = \frac{\partial}{\partial t}exp\left(-\frac{i}{\hbar}\hat{H}t\right)|\psi(0)\rangle \\
&= -\frac{i}{\hbar}\hat{H}exp\left(-\frac{i}{\hbar}\hat{H}t\right)|\psi(0)\rangle = -\frac{i}{\hbar}\hat{H}\hat{U}\,|\psi(0)\rangle = -\frac{i}{\hbar}\hat{H}\,|\psi(t)\rangle
\end{aligned}$$

Which turns out to be a Schrodinger equation with a time-independent Hamiltonian $\hat{H}$:

$$\hat{H}\,|\psi(t)\rangle = i\hbar\frac{\partial}{\partial t}|\psi(t)\rangle \tag{6}$$

5 Time & Clocks

At this point one ought to wonder what is time, what do we mean physically, when we say time. So far, in all our postulates we haven't defined or even mentioned time. Let's then look around at practice, which may suggest a natural proposition about time.

We definitely measure a passage of time with a help of clocks. A unit of time, is defined as a passage of a certain system(s) from one state to another, be it motions of planets, or atomic processes. And a moment in time is marked by some specific state of a certain system, like big arrow pointing at 5 (tea time), or a birth of Christ. More so, even equation (6) shows that time comes as a mere labelling of states that come one after another. Let's put these simple observations into a formal statement.

> **Time Hypothesis:** A change of states in quantum system is time.

In other words, if there is no matter, then there is no time to speak of.

Fine. So, if we have such a cozy relation between matter and time, how should we look for mathematical equations of motions, that give trajectories *in time*? We should look for a mathematical description of systems as if every one of them is a clock. Every little change of system's state should mark a next "tick" of time. So, if we define a minimal "tick" as Δt, and an amount of state's change as L, then trajectories should be such that a total change, or action, over any fixed period of time, $t_0 \dots t_1$, should be minimal. With action being

$$S = \sum_{t=t_0}^{t_1} L \Delta t \tag{7}$$

Voila! We just stated a principle of least action, coming from Time Hypothesis. And since using this principle has been producing working theories, we can be reasonably sure that Time Hypothesis has some validity.

Wait. Don't we all know from Special Relativity Theory that space and time go hand-in-hand, and speaking about one without the other has no merit fundamentally. Time Hypothesis itself talks about quantum systems that are effective objects, so, no wonder that it cannot be fundamental. Nonetheless, it is practical for certain questions.

6 Spacetime

Time Hypothesis implies that there is no time without matter. This has a charm of actual working relational definition of time & space, a la Leibniz and Mach. So, we should guess a spacetime postulate that implies that there is no spacetime without matter. And we have to use things from Matter Existence Postulate.

> **Spacetime Postulate:** Particle interaction events define spacetime points.

This does capture the main point, i.e. there is no spacetime without matter particles.

These events may have certain relations between each other, and these relations define properties of a perceived effective spacetime.

One such relation should be a causal one. Causal in a sense that incoming particles at some event A have to be outgoing ones from some other events

B's that are regarded as being in the past of A. This gives time-like relation between events.

Some or all of B's events may be not causally connected. Labelling these gives a space-like relation.

There is an interesting observation. If we take two effective electrons and rotate only one, electrons' spin orientation relative to each other will change. So, it is not unreasonable to suggest that a 3-D structure of space is an accommodation of spin relations.

And, given some mathematical quantative description of said relations, applying uniformity condition to them, should lead to a structure similar to Minkowski manifold. It has yet to be tried and calculated, but it is an obvious direction. Here we may also remark, that in this resultant spacetime a set of all particle events might be treated as usual quantum fields, with the possibility for slightly different counting of events, i.e. integration of currently divergent UV and IR parts. The reason for such speculation is that we take countable, infinitely, but still countable number of events, while common Minkowski manifold, and, thus, any fields on it, has uncountably many points in any finite volume. We may use uncountably large mathematical manifold, but with a properly defined procedure to prune it down to actual events that define an actual space, as per Spacetime Postulate.

7 Quantum Zeno Effect, Time Dilation, Gravity

By now we have two statements relating nature of time: one is a fundamental-level Spacetime Postulate, and the other is effective systems-level Time Hypothesis. Is it one too many, or else, how do these fit together?

We got to Time Hypothesis from Postulate IV, which, when expressed in usual quantum Hilbert space states formalism, talks about unitarity of quantum system's evolution. There are experiments that show a so-called quantum Zeno effect (QZE) in quantum systems, which show "inhibition of quantum evolution by measurement" (see [1], [2]). In QZE some quantum system is taken in an excited state, and, when left alone, system transitions to a ground state. Time for these transitions is known, and conceptually similar systems are even used as extremely precise clocks. But when an additional interaction is done to said system, transition time dilates. Intervening interactions are carefully timed, and they are of a "measure system state" type. Quantum system in QZE experiments is an effective system, consisting of a multitude of fundamental particle events. Any intervening interaction is an addition of extra fundamental events. In the light of Time Hypothesis, which says that a change of states in quantum system is time, we have to say that additional events dilate quantum system's time!

Time should be dilated from something. This something is a rate of events flow, which can come only from a flat fundamental spacetime. Quantum system's effective time is directed by time-like relations between spacetime events, and may coincide with them. But, since it can be dilated, we should not confuse an effective time with time-like relations of an underlying spacetime.

Time dilation looks similar to how particles are thought to get mass in the Standard Model through Higgs mechanism[4]. A load of additional events forces effective particle (electron, neutrino, etc.) to go slower, to "acquire mass", although underlying fundamental particle has no notion of mass.

The faster a particle goes, the more massive it will get. And, according to Special Relativity Theory (SR), the more time dilation it gets! Recall Twin Paradox from SR. One twin is rushing through the space, seeing different set of fundamental events, than another, that is sitting at rest. So, the first one gets his time relatively dilated.

Consider a pile of stuff like Jupiter, or Sun. Is it possible that a huge number of particles provides a huge number of additional events, so that, when you come close to it with an atomic clock (effective quantum system), it starts to tick slower? If so, it provides a basis for mapping regions of space onto a curved manifold, where on a scale of a tiny region, manifold's space directions may coincide with space relations of a flat fundamental spacetime, while in general it may have to be distinguished from such fundamental relations. And this can give us description of gravity, based on fundamental particle events.

A mathematical framework for this has yet to be found, and results have yet to be calculated and compared to experiments like Gravity Probe B. But it is strikingly suggestive that Higgs or Higgs-like mechanism is responsible for Special and General Relativities' effects.

[4]Existence of Higgs boson is a simple, but not the only version of Higgs mechanism

8 Discussion

Postulates I through IV can serve as a basis for mechanics even if we choose to postulate a separate container-like spacetime, in which all matter is to be present. There is no need for consciousness-induced collapse, there is no multitude of never-detectable worlds, and there is no privileged class of observers. Postulates provide physical meaning, which can later be packaged into appropriate mathematical form. This separation provides freedom to choose math, and a reason to drop mathematical solutions that may violate initial principles. And, with a two-tier postulates structure, there is an explicit connection between QM used in quantum computation and things done at LHC.

Preferred basis problem with quantum (effective) systems is absent in our treatment, cause every system is a collection of fundamental particles and events, and any switch into states of an alternative basis must reshuffle fundamental events, which does not seem to happen in reality. In other words, preferred basis problem is present in a theory that postulates, or quietly assumes, fundamental existence of certain mathematical spaces of quantum states, and later has to fix spaces' artifacts to match it to reality. Sort of like, putting a carriage (math) in front of a horse (physical essence), which may look beautiful, sometimes, but does not work all the time.

Let's consider an EPR-style experiment. At some event E_0 two particles are created with opposite to each other spin orientations, and so that incoming particles had total spin zero. Said particles may later enter respective events E_1 and E_2, where their spin is relevant to outcomes that eventually show up as measurements of their respective spins relative to some chosen spatial direction. E_1 and E_2 may have a space-like separation, and can be seen as occurring one before another, depending on a reference frame. The first measurement produces spin result relative to chosen space direction with a 50% probability, while the second measurement produces spin result relative to the first result with a 100% probability. If we assume a separate container-like spacetime, then a question arises about violation of locality, dictated by spacetime. Even though, no information is sent faster than a speed of light. May be such paradox will cease when we'll do a careful calculation within a mathematical spacetime framework based on our Spacetime Postulate, cause spacetime there is not a separate entity, but an effective thing, that is a result of relations between different fundamental particle events. Such is a motivation for a future work of finding mathematical expression of a suggested

Spacetime Postulate.

In closing we may add that relational spacetime immediately implies *a)* impossibility of travel back in time, and *b)* existence of physical vacua, i.e. no absolutely empty abstract space, except as a mathematical artifact. And, on a hope list for mathematical formulation[5] are *a)* MOND-style corrections to GR equation, since LHC shows absolutely no candidates for dark matter, and *b)* an explanation for expansion of the *whole thing*.

References

[1] P. E. Toschek and Chr. Balzer, "What Does an Observed Atom Reveal to Its Observer?", Laser Physics, Vol. 12, No. 2, 2002, pp. 253 261

[2] Erik W. Streed , Jongchul Mun , Micah Boyd , Gretchen K. Campbell , Patrick Medley , Wolfgang Ketterle , David E. Pritchard, "Continuous and Pulsed Quantum Zeno Effect", arXiv:cond-mat/0606430v1

[5]Where is an email of my old mathematics friend Grossmann?