Gravity & the magical "Born Rule": Physical implications

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Abstract

I. The arena of quantum theory is the abstract, unobserved and unobservable, M-dimensional Hilbert space $\neq$ spacetime. II. The arena of observations, and *all* events (*i.e. everything*) in the real physical world, is the classical 4-dimensional physical spacetime of general relativity. III. The "Born Rule" is the random process "magically" transforming I. into II. Formulations of quantum theory directly in real physical spacetime constitute examples of "locally real" theories (Clauser & Horne) and are *empirically refuted* by the numerous tests of Bell's theorem. When separated and treated correctly in this way, a number of fundamental problems and "paradoxes" of gravity vs. quantum theory simply vanish, such as the black hole information paradox, the cosmological constant problem and quantization of general relativity.

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1 Introduction: Quantum to Classical

I. Quantum theory lives in abstract Hilbert space: H^M which, more often than not, is infinite-dimensional H^∞ [1]. Complex quantum wavefunctions, ψ (= vectors in H^M), for N discrete quantum entities are defined in *configuration* space of $3N$ dimensions (if their spins are zero), $\psi = \psi(q_1, ..., q_{3N})$. The quantum state, *i.e.* the value of ψ, is determined by *simultaneously* giving *all* numerical values of the $3N$ variables $(q_1, ..., q_{3N})$. The time-dependence of ψ is only implicit, as t neither is an operator nor a variable in configuration space but merely a parameter, where $\psi_t = \exp^{-itH/\hbar}\psi_0$, and this abstract evolution occurs in complex Hilbert space, *not* in spacetime. The quantum states are normalized, $\int |\psi(q_1, ..., q_{3N})|^2 dq_1...dq_{3N} = 1$ (*i.e.* ψ lie at a point on the surface of the unit sphere in Hilbert space).

II. Classical physics lives in real four-dimensional spacetime: the Lorentzian manifold L^4 of general relativity.

III. On "measurement" the "Born Rule" [2] is *postulated* to irreversibly, instantaneously and randomly map H^M into specific points (= *events, i.e.* particular real outcomes) in L^4, with calculable probabilities. The joint probability density of *finding* N "particles" in N *detectors* in *real* space $(\bar{r}_1, ..., \bar{r}_N)$ at time t (*i.e.* in L^4) upon *"measurement"* is calculated by $|\psi(\bar{r}_1, ..., \bar{r}_N)|^2$. Observe that there is *no* real spatial dependence for ψ until this "measurement". The "fundamental" statistical character of "quantum theory" is actually *only* introduced here in III., due to "Born". Everything we ever measure (*e.g.* using laboratory "detectors"), perceive or experience occurs in *spacetime*, but it is only the Eigenvalues that can be observed in L^4, the quantum Eigenfunctions still reside in H^M (they constitute bases there) even after "Born". The "Born Rule" is "magical" in the sense that there is no physical dynamics underlying it *and* that it transforms *unobservable* H^M into *observable* events in L^4. On "measurement" the wavefunction ψ, with complex quantum amplitudes $c_n = \langle n|\psi\rangle$ in Eigenbase $|n\rangle$, randomly "collapses" ("jumps") to *one* of the Eigenfunctions $|n\rangle$ of the, for observables, allowed Hermitian operators $\hat{O}_n$ (assuring real Eigenvalues o_n)

$$\hat{O}_n\psi = \hat{O}_n \sum_n |n\rangle\langle n|\psi\rangle \xrightarrow{\text{“meas”}} o_k c_k |k\rangle. \tag{1}$$

Each individual "jump", $\psi \to |k\rangle$, resulting in the observed Eigenvalue, o_k, is *a priori* postulated to occur randomly, but with statistical probability (over *many* identical measurements) given by $|c_k|^2 = |\langle k|\psi\rangle|^2$. It is never the operators themselves that are observed, they only operate in Hilbert space *not* in spacetime. It is their Eigenvalues that are observed, and then only indirectly as a result of "measurement", Eq. (1), transforming I. into real events in II. as a result of III.

However, we only infer I. and III. *indirectly* through observations, experiments and experiences in II. - the only world we have any access to. *Observed* observables (= events) live in L^4. Quantum entities solely live in H^M and *have no classical properties*. The "measurement" transforms the infinitely many abstract quantum potentialities in H^M into perfectly mundane actual occurrences in L^4. Consequently, this shows that "decoherence" [3] *cannot* be a solution to the "measurement problem" [4] in quantum mechanics: i) It does not realize *any* objective outcome (unlike "Born"), ii) And if it did, it would mean that our real classical world would be *manifestly non*-local (as decoherence is based purely on the wholly deterministic non-local "dynamics" of I.) In pure quantum theory (without "Born") there cannot *be* any mixed states, as *probability presumes* prior measurement.

Hence we see that statistically correlated *observed* "quantum" non-locality in spacetime actually *only* arises through the magical "Born Rule".

"Reality" occurs *only* in the spacetime of events - where the actual events themselves are the fundamental, relativistically invariant and irreducible building blocks of objective reality [5]. It is only here, in II., that all experimental results, and everything else we ever perceive, actually occur. That is why Bohr was fond of saying: "There is no quantum world" [6] only an abstract quantum *algorithm*, I. together with III., allowing us to relate experiences in the real world II. - the only one. There is no "quantum" reality, there are no "quantum" events, only a *classical reality* and *classical events*. Every time a "quantum" probability is calculated, it is really a result of "Born" III., *not* of pure (unmeasured) quantum theory I. Likewise, there are no "quantum" particle reactions in *spacetime*, only observed consequences in L^4. So, only spacetime II. is really real as it consists of actual events, I. + III. merely an abstract and unobservable machinery, very much like a black box we cannot peer into, but with observable inputs and outputs. In a very real sense, the "quantum world" is operationally built up of real events in spacetime, not the other way around. Reality does *not* occur in Hilbert space H^M. This also means that there are no fundamental quantum entities in *spacetime*, only in (unobservable) Hilbert space. Wavefunctions are entangled [7] only in Hilbert space, *not* in spacetime.

The dynamical real spacetime itself (II.) is local. The entanglement superposition (in H^M) is *broken* by the measurement, I. $\stackrel{\text{III.}}{\longrightarrow}$ II., hence there is *never* any non-causal *entanglement* in real spacetime L^4. Only classical particles and fields are defined directly in L^4, including the gravitational fields $g_{\mu\nu}$ of general relativity.

III. is *non-local* [8] in real *spacetime*. It statistically correlates space-like separated events in our *real world*. "Born", III., is a random sampling, upon *"measurement"*, of the abstract, globally ever present and completely *deterministic* Hilbert space.

Unobserved quantum entities are always (merely abstract) "waves" *in* H^M, observed quantum entities are always "particles" manifested as events *in* L^4 - *there is never any "particle-wave-duality" in either space.* Specifically, there is never any causal "quantum-wave" propagation in spacetime. This means that classical physics, II., can *never* be the limit $\hbar \to 0$ of "pure" quantum theory, I. Furthermore, the quantum description of a system of N entities (for $N > 1$) cannot be embedded in real spacetime [9]. Abstract configuration space $(q_1, ..., q_{3N})$ and physical space (x, y, z) can coincide *only* if there is only *one* (spinless) quantum entity, actually *measured* at (x, y, z), in the entire universe (unfortunately *precluding* any interactions, experiments and observers), otherwise they are distinct - and actually the origin of most confusion.

2 Linearity vs. Non-linearity & Locality vs. Non-locality

2.1 Quantum Theory

Quantum theory for N spinless quantum entities lives in H^{3N}, an abstract, complex, *linear* (vector) space. The evolution in H^{3N} is continuous, linear [10], reversible, non-local (but merely abstractly/implicitly so) and deterministic (describable by differential equations). The wavefunction is not defined until/unless all points in configuration space $(q_1, ..., q_{3N})$ are used as input. The spacetime description is *only* appropriate for our *detectors and observations* in L^4 - not for the abstract theory supposedly "underlying it all" in H^M. No quantum fields ever "permeate" *spacetime.*

2.2 Classical Physics

Events define, and also constitute, dynamical classical spacetime, L^4. The dynamics is continuous, nonlinear, reversible, local, causal and deterministic (describable by generally relativistic covariant differential equations). This *nonlinear* classical dynamics, *e.g.* of relativistic gravity, evidently *cannot* result from "pure" linear quantum theory alone.

2.3 The magical "Born Rule"

The "Born Rule" is *discontinuous*, nonlinear, *irreversible* (entropy increasing [1]), non-local (explicitly - assumed to be instantaneous in *spacetime*), non-causal and *postulated* to be intrinsically/fundamentally *random*/probabilistic (*e.g.* giving no possibility of superluminal *signalling* despite the, now physical, non-locality in real spacetime). It is *not* describable by differential equations, or in any other dynamical way, instead being "magical". Observe that "Born" kills all superpositions (including entanglements) as the end result is a classical *probability* $\propto |\psi|^2$, not longer any interfering amplitudes/wave functions. This also means that there can be no superpositions in spacetime (or *of* spacetimes), as probabilities do not interfere, only add, forbidding any "quantum spacetime". It maps $H^M \xrightarrow{\text{“Born”}}$ into specific *outcomes* (= events) in spacetime, L^4. Observe that the *Eigenvalues* are the physical (and random) "observables" in L^4, *never* the Eigenfunctions/wavefunctions themselves (they perpetually live in abstract, complex Hilbert space). Expectation values, $\langle \hat{O} \rangle = \langle \psi | \hat{O} | \psi \rangle$, are statistical averages of many measured Eigenvalues in identically "prepared" systems, $|\psi\rangle$, and are predictable in a statistical sense only.

As Bell showed, *all* measurement results can ultimately be boiled down to *position* results [11] which, together with time, *are* the events in spacetime, L^4.

The *locality* assumption only applies to real physical spacetime, *not* to abstract Hilbert space where obviously everything is non-locally interconnected through the global configuration - *i.e.*, "unmeasured" quantum theory does not respect local Lorentz invariance - but this is irrelevant as Lorentz invariance is only *observed* in *spacetime* and H^M itself is *unobservable* in principle.

3 Quantum Space $\neq$ Real Spacetime: Gravitational Consequences

The non-locality in Hilbert space is an abstract "unphysical", ever-present, global non-locality. But it becomes a non-locality in real physical spacetime through "Born's Rule". The non-locality of measurement is evident already in the 1-particle case, as pointed out very early on by Einstein [12], but it becomes *experimentally testable* in N-particle entangled states. Originally, tests had $N = 2$, [13], [14], and *all* "locally real" [15] models formulated in real spacetime, L^4, are soundly *falsified* by these tests [9], *including* quantum mechanics and quantum field theory *formulated in real spacetime.* Hence, a truly relativistically invariant formulation of quantum theory in *spacetime*, which *includes* "measurement", could never be compatible with the non-locality of nature already observed in these tests as correlations in real outputs of real experiments in our real world II.

3.1 Consequence 1: No "Quantized" General Relativity

Apart from having entirely different mathematical structures, quantum theory and general relativity "live" in completely different spaces, which means that "Quantum General Relativity" and "Quantum Spacetime" are meaningless concepts [16]. Quantum theory lives in the abstract mathematical linear vector space H^M with perfectly deterministic and linear evolution. General relativity lives in, and actually constitutes, real physical 4-dimensional spacetime L^4 with its non-linear causal evolution of chains of "events" = the actual "happenings" that constitute the fundamental, irreversible, invariant "constituents" of spacetime, which, when warped by *classical* energy-momentum in *spacetime*, T^μ_ν, results in *classical* gravitation in L^4 through Einstein's equations $G^\mu_\nu = \kappa T^\mu_\nu$.

3.2 Consequence 2: No Cosmological Constant Problem

Virtual "particles" exclusively live in Hilbert space, *not* in physical spacetime. They never manifest into L^4 through "Born". The same applies for the "infinite zero-point energy" of the quantum vacuum in quantum field theory arising from "virtual particles". Which in turn explains why the cosmological constant, Λ, does *not* go to infinity, and hence why the physical cosmos (L^4) has been able to expand leisurely without ripping itself apart.

As "virtual particles" never physically manifest in spacetime they have no influence at all on the classical energy density T^0_0, or pressure T^i_i, in spacetime, so *no* effect on the expansion of the universe given by Einstein's equations: $G^\mu_\nu = \kappa T^\mu_\nu + \Lambda g^\mu_\nu \stackrel{?}{=} \kappa T^\mu_\nu + \kappa\langle 0|\hat{T}^\mu_\nu(virtual)|0\rangle \equiv \kappa T^\mu_\nu$.[1] In fact, there is *no* instance where this "vacuum energy" is actually physically needed [17].

3.3 Consequence 3: No Black Hole "information paradox"

As wavefunctions, for $N \geq 2$ quantum entities, are objects in Hilbert space with global entanglement through $(q_1, ..., q_{3N})$, *not* in L^4, they are unaffected by causal horizons in spacetime, meaning that quantum entities inside the horizon are always accessible by entangled quantum entities outside the horizon - nullifying, for *quantum theory*, *e.g.* the classical one-way membrane of a black hole event horizon - and hence potential information is in principle always accessible across horizons. A causal probability current in *spacetime* is definable, and conserved, only for a single, non-interacting particle, making it physically irrelevant. For N quantum entities, entangled or not, *no* conserved probability current exists in spacetime [9], and hence can never "flow" causally. (And neither in Hilbert space as "probability" requires that "Born" already has occurred.) The abstract non-locality in Hilbert space binds quantum entities into a single global irreducible ψ. "Born" then binds actual events non-locally in real spacetime, regardless of spacetime-interval separation. This resolves the quantum information paradox [18] for black holes, making it a non-question.

[1] We have here assumed a Λ that is solely due to the presently very fashionable, albeit completely *hypothetical*, "Dark Energy", *i.e.* "quantum vacuum energy". As Λ in *classical general relativity* is merely a free parameter we can *choose* it to have any value whatsoever to comply with cosmological observations (*e.g.* finite and *very small*). Such a $\Lambda_{classical}$ would give a *curvature* to spacetime in the absence of T^μ_ν (*i.e.* even in the *classical* vacuum) but $\Lambda_{classical}$ is *not* a classical vacuum energy, which by *definition* is *identically zero.* It is a geometric curvature of empty spacetime itself.

4 Summary & Conclusion

"Pure" quantum theory, I., is *implicitly* non-local, but the non-locality is abstract (not observable) as it does not "live" in spacetime but in Hilbert space.

The "Born Rule", III., is *explicitly* non-local for entangled quantum systems - it correlates spacelike separated *events* in *real* spacetime, as required by Bell's theorem [13] and its empirically validated requirement of a non-local reality [14].

"Reality", II., occurs only in the spacetime of *events* (which are the fundamental "building-blocks" of objective reality) *not* in quantum Hilbert space.

The fact that quantum systems comprising more than one quantum entity $N > 1$ *cannot* be embedded in spacetime has very deep, profound and startling consequences. The classical world is a necessary additional independent structure not derivable from quantum theory. Furthermore, the events constituting spacetime of general relativity *is* this classical structure. The geodesics in curved spacetime *are* gravity, and they consist of classical *events*. Hence, gravitation is required to make the formal quantum theoretical coexistence of many mutually incompatible possibilities result in the concrete reality of our normal world - making gravitation the most fundamental interaction.

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