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How Classical Friction Arises from Frictionless Quantum Theory

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Abstract

Quantum theory lives in abstract, infinite-dimensional, complex, linear Hilbert space, is unitary and non-dissipative, and has been proven not to be embeddable in spacetime for $N \geq 2$ quantum entities. It is per definition *unobservable* (in itself). Classical physics describes the causal, nonlinear dynamics of actual *events*, which lie in, and also define, four-dimensional spacetime. The "Born Rule" maps abstract quantum theory into events, *i.e.* real outcomes, in classical spacetime. It must be postulated separately and *cannot* be deduced from quantum theory, as it is both *non*-unitary and irreversible, *i.e.* dissipative. Hence, the "Born Rule" is ultimately and fundamentally responsible for dissipation, *i.e.* friction, and therefore all evolving complex systems, in the classical, observable world.

1 Introduction

Friction (dissipation) is crucial for structure formation at all levels [1], and hence for life itself [2]. Furthermore, the observed natural world is never non-dissipative/conservative, except approximately (for example Newtonian gravity).

To successfully explain how friction fundamentally arises in the classical world requires two criteria. It should:

i.) show how friction emerges at the classical level even though absent at the quantum level where elementary quanta evolve through conservative fundamental interactions.

ii.) give the resulting nonlinear dynamics [3] of the classical, directly perceived, world from the postulated exactly linear evolution of, never directly perceived, quantum theory.

Friction is paramount for structure formation in the real world as it can bleed off energy, permitting structures of all possible sizes and amazingly novel configurations to form. One striking example being the obvious broken time-symmetry, *i.e.* energy non-conservation, of living things. It is also necessary for convection, turbulence, dissipative chaos, and in fact, as we shall see, all phenomena of the observed world.

2 Quantum Theory

Quantum theory exclusively lives in abstract linear Hilbert space, which, more often than not, is infinite-dimensional [4]. Complex quantum wave functions, $|\psi\rangle$ (vectors in Hilbert space), for N discrete quantum entities are defined in *configuration* space of $3N$ dimensions (if their spins are zero), $|\psi\rangle = |\psi(q_1, ..., q_{3N})\rangle$. The quantum state, *i.e.* the value of $|\psi\rangle$, is determined by simultaneously fixing all numerical values of the $3N$ variables $(q_1, ..., q_{3N})$. The time-dependence of $|\psi\rangle$ is only implicit, as t neither is an operator nor a variable in configuration space, just a parameter, where $|\psi\rangle_t = \exp\left[-it\hat{H}/\hbar\right]|\psi\rangle_0$, and this non-dissipative (unitary) Hamiltonian evolution ($\hat{H}$) occurs in abstract, complex Hilbert space, *not* in spacetime. In fact, before "measurement", there is no spacetime description of $|\psi\rangle$, so relativistic causality is not even definable. The quantum states are normalized, $\int |\langle\psi(q_1, ..., q_{3N})|\psi(q_1, ..., q_{3N})\rangle|^2 dq_1...dq_{3N} = 1$, meaning that $|\psi\rangle$ lie at a point on the surface of the unit sphere in Hilbert space.

If $N \geq 2$, the quantum evolution cannot be embedded as dynamics in physical spacetime [1] [6].

3 The "Born Rule"

The "Born Rule" is what bridges unitary quantum theory into observable (classical) nature. As it is non-unitary, it cannot result from unitary quantum theory but is postulated separately. It is also *only* here that the "uncertainty",

[1] In essence, this was known already to Schrödinger [5].

i.e. the probabilistic nature, of the quantum formalism arises. The "fundamental" statistical character of "quantum theory" is thus actually solely due to the separately postulated "Born Rule".

On *"measurement"* the "Born Rule" [7] is *postulated* to irreversibly, instantaneously and randomly map quantum theory into specific points (= *events* = real objective physical outcomes) in spacetime, with calculable probabilities. For example is the joint probability density of *finding* N "particles" in N *detectors* in *real* three-dimensional space ($\bar{r}$) at time t upon "measurement" calculated by $|\langle\psi(\bar{r}_1,...,\bar{r}_N)|\psi(\bar{r}_1,...,\bar{r}_N\rangle|^2$. Observe that there is *no* real physical spatial dependence for $|\psi\rangle$ until "measurement". Everything we ever measure (*e.g.*, using laboratory "detectors"), perceive or experience occurs in *spacetime*, but here only real Eigenvalues can be observed, the corresponding complex quantum Eigenfunctions still reside in Hilbert space (they constitute bases there) even after the "Born Rule" is applied.

Anytime the quantum formalism is used to make a prediction of *any* observable quantity, the "Born Rule" has already (explicitly or implicitly) been utilized [8]. Abstract Hilbert space itself, where the quantum wave functions perpetually reside, is always unobservable.

3.1 Dissipation is due to the "Born Rule"

The irreversibility of the "Born Rule", the emergence of objective classical events that cannot be undone, is what ultimately gives rise to dissipation.[2] So, contrary to common belief, friction *is* a fundamental law of nature. Only irreversible processes contribute to entropy production, and irreversibility - the "arrow of time" - is fundamentally due to the "Born Rule", as the equations of both quantum theory and classical physics are perfectly reversible. It is this explicit introduction of a *fundamental* probability, as a law of nature, that removes the reversibility and defines a direction of time. The second law of thermodynamics, the distinction between future and past, results through the "Born Rule", not the other way around. (The normal explanation of the second law needs an "arrow of time", and cannot *deduce* it.) If a conscious observer

[2] A purely unitary theory, like *e.g.* Everett's "relative state"/"many-worlds"-interpretation, cannot generate dissipation. Nor any actual outcomes/results/events whatsoever as quantum superpositions now persist indefinitely. None of the parallel "many worlds" are real (manifested), as they all lack a spacetime of events. Also, as the total dynamics now is *linear* it can neither (in any of the "many-worlds") reproduce the nonlinearities we see all around us [8]. In fact, Everett's interpretation is just orthodox "pure" (unmeasured) quantum theory, but where the superposition-components are interpreted to, somehow, lie in different "worlds" rather than in one and the same (orthodox). But as wave functions live in Hilbert space, *not* in spacetime, this seems completely irrelevant.

(*e.g.*, whose memory [3] evidently breaks time-symmetry) is ultimately needed to end the von Neumann-chain of ever larger quantum superpositions [10, 11] in order to finally effectuate "measurement", it itself would be the irreversible, dissipative, entropy-producing agent.[4] If we, for a closed system, denote the entropy by S and the information by I, and as $S+I = constant = S_{max} = I_{max}$, a *local* gain of information is accompanied by a *local* decrease of entropy [5], paid for by a global *increase* of entropy, due to Born dissipation in the larger open system, ultimately as a result of "measurement" - as entropy [6], which is a *probabilistic* concept, presupposes actual outcomes [7]:

3.1.1 Superposition States

Before measurement, a quantum system typically exists in a superposition of states, represented by a wave function [8]

$$|\psi\rangle = \sum_i c_i |\phi_i\rangle,$$

where c_i are the complex amplitudes associated with each possible Eigenstate $|\phi_i\rangle$. This is possible *only* because of the perfect *linearity* of quantum theory, stemming from its foundational "linear superposition principle"-postulate. The "Born Rule" results in the measured system, non-dynamically, "jumping"/"collapsing" to one specific Eigenstate $|\psi\rangle \xrightarrow{\text{“Born”}} |\phi_k\rangle$ with probability $|c_k|^2 = |\langle\phi_k|\psi\rangle|^2$.

Dissipation: The relative phases and amplitudes $\{c_i\}$ of the original superposition are destroyed by measurement, meaning information about coherence between states is lost, increasing entropy [9].

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[3] Compare "Maxwell's demon" [9]. [4] A computer requires irreversible "measurement" operations that generate $> kT$ heat and corresponding entropy per typical logical function [12]. [5] For example, in living things. [6] And thus information. [7] The basis-independent von Neumann entropy [11], $S_{VN} = -tr(\rho\, ln\rho)$, is nonlinear in the probability density operator, ρ, so the second law is expressible in macroscopic (="measured") variables like temperature and matter density only near equilibrium - *i.e.*, for "mild" irreversible transitions from one equilibrium state to another. The irreversible process itself is outside the scope of ordinary thermodynamics. [8] "Mixed" states, with probability density operator $\rho = \sum_i P_i |\psi_i\rangle\langle\psi_i|$, include classical probabilities, $\sum_i P_i = 1$, so (implicitly) assumes "measurement" (*e.g.*, "preparation") has *already occurred*. The $\{|\psi_i\rangle\}$ are generally *not* a basis, so ρ is non-diagonal. For a pure state (*i.e.*, wave function), where *one* $P_i = 1$, $S_{VN} = 0$. [9] The unitary evolution of quantum theory takes pure states into pure states and hence generates no entropy. For that, "measurement" is needed.

3.1.2 Potential Outcomes

Prior to measurement, the wave function encodes the probabilities of *all* possible allowed outcomes, given by

$$\sum_i |c_i|^2 = 1.$$

After measurement, only *one* outcome is observed, and the resulting wave function no longer contains information about the previously possible outcomes.

Dissipation: The probabilities of outcomes not realized are no longer retrievable after measurement, resulting in irreversible loss.

3.1.3 Interference

In quantum systems, the superposition of states (in Hilbert space) allows for interference effects. One well-known example is the double-slit experiment. If provisions are made for measuring "which slit" a particle goes through, the interference effect disappears; the "Born Rule" eliminates the coherence necessary for interference, as the resulting "which slit"-probabilities now only can *add* - not interfere.

Dissipation: The ability to observe interference patterns, which requires knowledge of phase relationships, is irreversibly lost.

3.1.4 Time-irreversibility

The unitary quantum evolution of the wave function is completely reversible (one-to-one), meaning that previous states of the system can, in principle, be reconstructed as easily as subsequent states can be predicted. (That time-reversal, mathematically, implies complex conjugation is *physically* irrelevant as neither $|\psi\rangle$ nor $\langle\psi|$ are observable.) The "Born Rule" is non-unitary (*many-to-one*) and introduces an irreversible element in real *spacetime*, while also effectively destroying the original quantum state in Hilbert space.

Dissipation: The specific wave function prior to measurement can no longer be reconstructed, the information loss resulting in entropy increase.

3.1.5 Entanglement

For entangled quantum systems, measurement of part of the system collapses the entire entangled state. The global entangled state (in Hilbert space), which implicitly (in spacetime) encodes space-like correlations between subsystems, is replaced with localized outcomes.

Dissipation: The complete information in the entangled wave function is, nonlocally, replaced with localized, but conditionally correlated, classical measurement results.

3.1.6 Decoherence is *not* the answer

"Decoherence" [13] - the purported randomization of linear quantum phase-relations, allegedly suppressing quantum interference terms - is circular, in order to obtain actual results implicitly assuming the conclusion it is trying to prove [14]. The decoherence "solution" requires non-unitary/irreversible "collapse" to remove this circularity. It relies on taking the trace of the probability density, ρ (which itself does *not* correspond to an observable), with a Hermitian operator $\hat{A}$ corresponding to some observable A; $tr(\rho\hat{A})$ which is just the expectation value $\langle\hat{A}\rangle$, *i.e.* implicitly *assuming* the "Born Rule", and hence cannot result from "pure", unmeasured, quantum theory [10, 11, 15, 16, 17]. Instead, decoherence must at some stage *utilize* the "Born Rule" to obtain *real outcomes*. Also, both the quantum "system", and its quantum "environment" to be traced over (to obtain the so-called reduced density of the "system" alone, which *erases* all potential information in the "environment"), live in Hilbert space, *not* in physical spacetime. No wave functions ever "permeate" or "traverse" spacetime, they *only* live in the abstract, unobservable, space. Furthermore, the division "system"/"environment" is *arbitrary* in unitary quantum theory, as everything is part of a total (reversible and deterministic) $|\psi\rangle$. For "system" to make sense, it has to be "measured", *i.e.* implicitly or explicitly requiring the (irreversible and stochastic) "Born Rule".

4 Classical Physics = *Observable* Physics

This is the only level we have any direct contact with. It is the arena of all our experiences in the form of relativistically invariant events, *i.e.* actual *occurrences*, in spacetime. There is no "particle/wave-duality" in *spacetime*, as "particles" (manifested as localized events) live in spacetime, while quantum "waves" exclusively live in Hilbert space, *not* spacetime.

General relativity, which is the theory that describes the world of these objective events and their causal relations, is nonlinear (as is all of classical physics) because of the field equations governing it, automatically including the gravitational geodesic equations of motion. The Einstein field equations, $G_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$, involve terms highly nonlinear in the spacetime metric tensor, $g_{\mu\nu}$, and its derivatives. This nonlinearity arises because the gravitational field, in addition to coupling to matter, also couples to itself. While the matter (included in the energy-momentum tensor, $T_{\mu\nu}$) locally couples to gravity, the gravitational field couples to itself through the Einstein tensor, $G_{\mu\nu}$.

Moreover, in the real *observable* world, systems are always dissipative with shrinking phase spaces (if undriven), non-dissipative/conservative systems with constant, incompressible phase space volumes being just mathematical idealizations. The non-unitary, irreversible "Born Rule" is the only place where phase space volume conservation can be broken, as both ("pure"/unmeasured) quantum and classical evolution are reversible.

For example, Ehrenfest's theorem [18] gives, in the mean, classical equations of motion

$$\frac{d\langle\bar{p}\rangle}{dt} = -\langle\nabla V(\bar{x})\rangle, \tag{1}$$

where $\hbar$ is no longer anywhere to be found, the explicit quantum-dependence having vanished through the "Born Rule", as expectation values are perfectly mundane, non-quantized and real.

Generally, the expectation value of any operator $\hat{A}$ (acting in *Hilbert space*) corresponding to some classical observable A (in *spacetime*) is its average *measured* value

$$\langle\hat{A}\rangle \equiv \langle\psi|\hat{A}|\psi\rangle = \sum_{a'}\sum_{a''}\langle\psi|a''\rangle\langle a''|\hat{A}|a'\rangle\langle a'|\psi\rangle = \sum_{a'} a'|\langle a'|\psi\rangle|^2, \tag{2}$$

where a' is one specific individually measured value, and $|\langle a'|\psi\rangle|^2$ the probability for obtaining that value. The term $|\langle a'|\psi\rangle|^2$ shows that the "Born Rule" has been applied, physically meaning that measurement has been effectuated, turning superposed quantum "ghostliness" (*only* ever present in *Hilbert space*) into one concrete objective event in classical spacetime.

As an example, the gravitational potential $V(\bar{x}) \propto 1/|\bar{x}|$ inserted into Eq. (1) gives the analogous macroscopic Newtonian gravitational *nonlinear* dynamics; and Hamiltonian chaos [19] if the number of interacting bodies is $N \geq 3$. Of course, Newtonian gravity is conservative due to its spherically symmetric potential nature (only position dependent). In general relativity, there are ten dynamical gravitational fields (the independent spacetime metric components) at every single point that *can* exhibit dissipation (*e.g.*, gravitational waves). Structure formation requires both nonlinearity and non-equilibrium - which in turn requires dissipation [1], allowing, *e.g.*, low-dimensional attractors to form from much larger (even infinite-dimensional) systems.

5 Conclusions

The only place in fundamental theory where dissipation, *i.e.* friction, enters is in the "Born Rule" - the irreversible "collapse" that turns linearly superposed, classically incompatible, coexisting complex quantum possibilities (also called probability amplitudes) into concrete classical outcomes in the real world, *i.e.*, as *events* in *spacetime*. That quantum probabilty amplitudes "live" in Hilbert space, and classical probabilities (manufactured by the "Born Rule") "live" in classical spacetime, removes (almost) all "paradoxes" of quantum vs. classical - except the "Born Rule" itself [8].

It is also via the "Born Rule" linear Hilbert space quantum evolution turns into classical nonlinear dynamics, needed to explain the complexity in the observed world - the *whole* is *not* merely the linear sum of the parts, and "effects" are *not just proportional* to "causes". This also clearly shows that classical physics is *not* a macroscopic limiting case of "pure" (unmeasured) quantum theory.

In summary:

I: Quantum Theory	***II: "Born Rule"***	***III: Spacetime***
Wave function	Wave function → Events	Events
Relativistically undefined[10]	Not relativistically invariant[11]	Relativistically invariant
Unitary	Non-unitary	Causal[12]
Reversible evolution	Irreversible mapping	Reversible dynamics[13]
Nonlocal (in *Hilbert space*)	Nonlocal (in *Spacetime*)[14]	Local
Linear	Nonlinear	Nonlinear
Continuous	Discontinuous	Continuous
Deterministic	Stochastic[15]	Deterministic

Assuming that the universe was created [20] in a pure quantum state (zero entropy) subsequent and successive "measurements" create local structure and evolving complex systems at the expense of global entropy increase through the fundamental dissipation of the magical "Born Rule" [8].

[10] Although the *classical* Hamiltonian/Lagrangian *before* "quantization" can be relativistically non-invariant (*e.g* Schrödinger equation), or invariant (*e.g* Dirac equation/Quantum Field Theory), the wave functions of the quantized theory do *not* live in spacetime. [11] The "forbidden" correlation of space-like separated events, as confirmed in real experiments testing Bell's Theorem, is evident in Fig.1. [12] With the possible exception of black holes, and singularities and/or event horizons in other, *e.g.* cosmological, settings. [13] In principle, if not in practice. Even though the fundamental dynamical equations of classical physics are reversible, the observed world "inherits" the irreversibility of the "Born Rule". [14] The nonlocality is also evident in Fig.1. [15] This postulated *fundamental* randomness is what saves the world from relativistic paradoxes. Despite the *physical* "spooky action at a distance"-nonlocality, any "signals" will appear random unless/until *compared* (which requires $v \leq c$) and actually show "superluminally"-linked correlations.

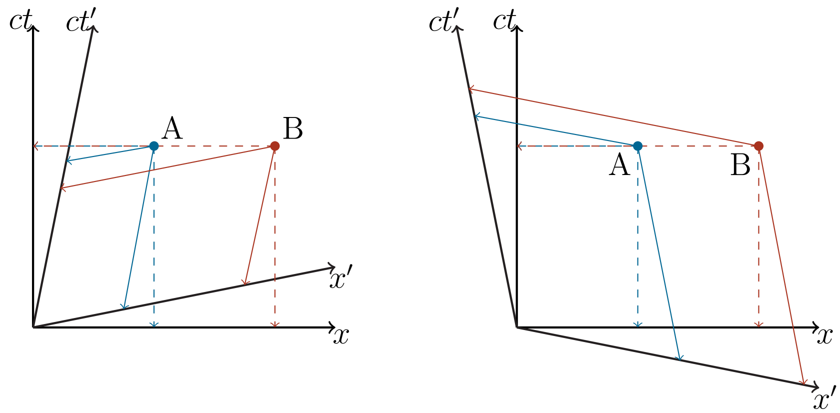

Figure 1: Minkowski diagram for *measurement* of entangled Bell-correlated events, A and B, simultaneous in the lab (ct, x), with reference frames moving inertially relative to the lab (ct', x') in which A and B are non-simultaneous: Left $v \approx 0.2c$ (B prior to A), Right $v \approx -0.2c$ (A prior to B). This results for arbitrarily small space separation $\epsilon = |x_A - x_B|$ and any $v \neq 0$, assuming that $t_A = t_B$ (simultaniety in the lab-data), calling "cause-effect" (which entangled event "collapses" which?) into question, especially as $|t'_A - t'_B| \to \infty$ as $v \to c$: Why should the "collapse" be instantaneous *only* in the lab-frame, when there exist infinitely many other frames equally valid and real? Also, if thus "switching" cause-and-effect (which event is measured "first" and thus determines the other) there is no reason why the (postulated) *random* result in left-moving frame should be the same as that in a right-moving frame. But they *must* be as they are *results*, *i.e.* *events* in classical spacetime. This clearly shows that the "Born Rule" is nonlocal in spacetime, but does not explain why (potentially) different outcomes never occur in different frames, as the "Born Rule" is *postulated* to be *fundamentally* random. If nature instead is superdeterministic, so that results A and B are predetermined - like "pebbles" (events) fixed in the invariant 4D spacetime block - it can explain why events in all frames agree (without any "spooky action at a distance"). But that is unfortunately untestable in principle, as experimenters then would not have "free will" to choose what to measure. Then again, "free will" is not part of *any* known physical laws; both quantum theory and classical physics being completely deterministic, and the "Born Rule" (supposedly) random. "Free will" is probably directly related to *consciousness*, an unsolved (unsolvable?) enigma, apparently lying outside, or transcending, all known physical laws and even the very "scientific method" itself (of hypothesis → tests → better hypothesis → new tests → ...) which *presupposes* conscious scientists and thus cannot be used to neither deduce nor test consciousness.

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