

Quantum qRules: Foundation Theory

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11 December 2008

Three qRules governing wave collapse are given in this paper that provide a foundation theory of quantum mechanics. They are empirical regularities that are known to be valid in macroscopic situations. When projected theoretically into the microscopic domain they predict a novel ontology, including the frequent collapse of atomic wave functions. Future experiments can potentially discriminate between this and other foundation theories of quantum mechanics. Important features of the qRules are: (1) they apply to individual trials not just to ensembles of trials, (2) they are valid independent of size or mass (microscopic or macroscopic), (3) they allow all observers to be continuously included in the system without ambiguity, (4) they account for the collapse of the wave function without introducing new or using old physical constants, (5) they allow energy and momentum to be conserved in an individual collapse, (6) they generate wave reductions that are independent of any outside observer or measuring device, (7) they provide a high frequency of stochastic localizations of microscopic objects independent of macroscopic objects, and (8) they are formulated in a covariant language that makes them useful beyond non-relativistic quantum mechanics. Keywords: foundation theory, measurement, qRules, state reduction, wave collapse.

Introduction

The *qRules* are three auxiliary rules that guide the application of Schrödinger's equation. They are a set of instructions that describe how stochastic choices cause the wave to collapse and "start over" with new boundary conditions.

The Born rule is an auxiliary rule of standard quantum mechanics; however, it is not a necessary tenet of quantum mechanics. Probability can be introduced into the theory through *probability current*. This has been done in three cases: The qRules of this paper, the *nRules* [1, 2] and the *oRules* [3, 4]. The auxiliary rules of standard quantum mechanics that do not use probability current in this fundamental way will be referred to as *sRules*. The three qRules of this paper are a simplification of the four nRules. The conclusions of both are roughly the same, but the qRules are axiomatically preferable.

Theories based on the Born rule give the probability that a system will be found in a certain state at a time T after the initial time t_0 . In contrast to this, qRule equations give a running account of the probability that there will be a collapse of the wave at a time t after t_0 . The Born rule is concerned with the *result* at some time T , and the qRules are concerned with the *process* that leads to a collapse. These two approaches are formally equivalent, but the qRules make a different empirical connection. They have the advantage for reasons having to do with the status of observers in quantum mechanics as will be shown.

It is found that the qRules allow the *primary* observer to be continuously included in the system. This is similar to classical physics in that an observer who investigates an external system has the option of extending the system to include himself, thereby allowing him to theoretically describe his own experience from moment to moment. Standard quantum mechanics does not let that happen. The Born rule supposes that the primary observer remains outside the system. He peeks at the system from time to time to determine the Born connection at any moment, but he cannot *follow* internal processes. On the other hand, the qRules equations follow internal processes. This difference has to do with the different ways that probability is introduced – as a result or as a process. Physics with the Born rule is portrayed as an epistemology that excludes ontology; whereas the qRules support a “non-classical” ontology that embraces probability (applied to individual processes) as a primitive idea.

Another consequence is that all *secondary* observers can be included in the system in an unambiguous way. The qRules remove the paradox associated with the Schrödinger cat experiment and with all other ambiguities that result when a secondary observer is admitted into the system. Some sRules also allow a secondary observer to exist without paradox, such as the many world thesis of Everett and the GRW/CSL theory of Ghirardi, et. al.[5-7] However, under the qRules *all* conscious observers have an unambiguous place in quantum mechanics – as they do in classical physics.

Experimental prospects are discussed in the “Experimental Test” section of this paper.

Some Definitions

If a component $\psi(x_1, x_2, x_3, \dots, t)$ of a wave function includes all the (anti)-symmetrized particles in the universe, and if it is not just a component of an expansion in some representation, then we say that it is *complete*. The corresponding square modular or *sm-component* is given by

$$u(t) = \int \psi^*(x_1, x_2, x_3, \dots, t) \psi(x_1, x_2, x_3, \dots, t) dx_1 dx_2 dx_3 \dots$$

where all possible representations of the particles are integrated out. So an sm-component is also complete in that it too contains all the particles in the universe, and it too is not just one component of an expansion in some representation. It is *trans-representational* – a function of time only.

If the isolated system under consideration consists of several distinct parts like an atom a , an elementary particle p , and a macroscopic instrument m , then an sm-component containing these parts can be written

$$u(t) = apm \otimes E(t)$$

where E is the entire universe apart from the system of interest. If this is written

$$u(t) = apmE(t)$$

then the environment may or may not interact with the system as will be specified.

Let a wave function be given by the sum of two complete orthogonal components

$$\Psi(x_1, x_2, x_3, \dots, t) = \Psi_a(x_1, x_2, x_3, \dots, t) + \Psi_b(x_1, x_2, x_3, \dots, t)$$

The corresponding *qRule equation* is then the sum of two sm-components with no cross term.

$$U(t) = u_a(t) + u_b(t) \tag{1}$$

The $u_a(t)$ and $u_b(t)$ are also called *orthogonal*.

Suppose the component u_b is initially equal to zero but increases in time as u_a decreases, thereby preserving the total square modulus as in any ‘measurement’ interaction. It is character-

istic of a measurement that the measured state ψ_b is orthogonal to the initially given state ψ_a , insuring that the passage from the u_a to u_b is an *orthogonal quantum jump*. The other condition implicit in measurement is that the interaction is *non-periodic*. That is, it does not oscillate like simple harmonic motion with a characteristic frequency. The interaction may be thought of as being ‘irreversible’ if it is clear that that does not refer to the thermodynamic meaning that is only statistically significance.

Probability is introduced in these rules only as it appears in the second qRule given below – as related to probability current rather than to square modulus. The understanding is that probability applies to *individual trials* rather than just to ensembles of trials. Our focus is on the individual, so qRule equations like Eq. 1 refer to individual processes.

We distinguish between *ready* components and *realized* components, where only realized components are understood to have empirical significance. This will be clarified in the examples to be given. Ready components are underlined throughout, whereas realized components appear without an underline. The term ‘component’ in this paper will be understood to mean sm-component as opposed to wave component.

The qRules

The first qRule describes how ready components are introduced into equations.

qRule (1): *If a non-periodic interaction results in an orthogonal quantum jump to an sm-component, then that component is a ready component. A ready component remains ready until it is stochastically chosen.*

[**note:** This rule tells us that the second component in Eq. 1 is a ready component, and that the first (initially given) component is realized. The interaction in Eq. 1 will therefore appear in the form $U(t) = u_a(t) + \underline{u_b(t)}$ with the second component underlined.]

The second qRule establishes the existence of a stochastic ‘trigger’, and identifies ready components as the ‘targets’ of stochastic choice. The change per unit time of square modulus of an sm-component is given by the square modular current J flowing in or out of it, and the total square modulus of the system (i.e., the magnitude of U in Eq. 1) is given by σ .

qRule (2): *A systemic stochastic trigger can only strike a ready component, and it does so with a probability per unit time equal to the positive probability current J/σ flowing into it from a realized component.*

[**note:** The division of J by σ automatically normalizes the flow of probability at each moment of time. Currents rather than functions are normalized under these rules. Notice that the target of stochastic choice is a ready component that might be a microscopic or a macroscopic component. The collapse mechanism does not select a proton or a measuring device as do other theories. Instead it selects non-periodic orthogonal quantum jumps for state reduction.]

The collapse of a wave is given by qRule (3)

qRule (3): *When a ready component is stochastically chosen it will immediately become a realized component with a finite magnitude, and all other components will go immediately to zero.*

[**note:** The survivors of a collapse will generally undergo transient uncertainty of energy associated with $\Delta E \Delta T$, where ΔT begins the moment following collapse. This description does not distract from the claimed instantaneousness of the collapse itself.]

[note: Every sm-component of a qRule equation has the same energy and momentum because each contains all the particles in the universe. After the transient uncertainty ΔE has died out, energy and momentum are conserved in a collapse in which one sm-component is replaced by another. The collapsed component does not have to normalize to 1.0 for reasons that were given under qRule (2).]

[note: The collapse is instantaneous because an sm-component cannot linger between being not-empirically real and empirically real. There is no “in-between” existence and non-existence.]

Notice that the qRules are an empirical description of what happens macroscopically, and by theoretical extension, what happens microscopically as well. There is no attempt to unify these rules with the dynamic principle, although that may possible.

A Particle Capture

This section is the first macroscopic application of the qRules. It involves an elementary particle that is captured by a detector.

Apply Schrödinger’s equation to a particle p interacting with a detector d . The interaction beginning at time t_0 is given by the qRule equation of sm-components

$$U(t \geq t_0) = pd_0(t) + \underline{d}_1(t) \quad (2)$$

where the second component is zero at t_0 and increases in time. The free particle p here interacts with the ground state detector d_0 producing a probability current flow from the first component to the second, where the latter is the detector in its capture state. The gap between these two components is orthogonal because the detector states d_0 and d_1 are orthogonal. The interaction is also non-periodic. In addition, each component in Eq. 2 is assumed to be multiplied by the associated total environment (not shown), assuring detector decoherence and satisfying the requirement that each component is complete. Therefore, the gap given by the + sign satisfies qRule (1), making $\underline{d}_1(t)$ a ‘ready’ component as indicated by the underline.

Since positive probability current flows into the ready component it is subject to a stochastic hit as specified by qRule (2). If that happens at a time t_{sc} , then qRule (3) will require a state reduction giving the qRule equation

$$U(t \geq t_{sc} > t_0) = d_1(t) \quad (3)$$

The ready component in Eq. 2 will also be called the *launch* component because it provides the launch $d_1(t_{sc})$ into the new solution in Eq. 3.

This example shows how a theory based on probability current contrasts with standard quantum mechanics that is based on the Born interpretation of probability. In the Born case, the theory gives the probability that the system will be found in a certain state at a time T after the initial conditions are established at t_0 . In the present case, the theory provides a running account of the probability that a stochastic choice will occur at a time t after t_0 . This is the reason for the distinction between ready components and realized components. The first component pd_0 in Eq. 2 is ‘realized’ (i.e., an empirical reality) *until* the stochastic hit at t_{sc} , at which time the second component becomes realized in its place. Before that time the second component \underline{d}_1 is only a ‘ready’ component having (as yet) no empirical significance – it is not yet a physical reality.

Energy and momentum are conserved in the collapse because both the particle and the detector collapse together.

It is possible that the particle will not be captured by the detector, in which case Eq. 2 will not collapse to Eq. 3. The first component pd_0 will then continue to be realized and the second component will become irrelevant.

There is a caveat that is not dealt with here. The detector has two different kinds of variables: Those that are affected by a stochastic hit and those that are not. It is sometimes important to make this distinction because the Schrödinger equation makes the distinction. A general way of handling this difference is developed in Appendix I, and its application to detector variables is given in Appendix II.

Free Neutron Decay

When the qRules are applied to microscopic systems they become ‘speculations’ rather than empirically knowable regularities. This section is the first example of that kind. The qRules are here projected into a realm in which the resulting ontology is discernable, although of course it is non-classical.

A *free neutron decay* is given by the qRule equation

$$U(t \geq t_0) = n(t) + \underline{ep}\bar{v}(t)$$

where the second component is zero at t_0 and increases in time. It is a ready (launch) component, although it not necessary to underline the entire component – one state will do. In order to satisfy the requirement of completion, each component is multiplied by the total environment (not shown) even though the neutron and its decay products are an isolated system. As before, the decay state $\underline{ep}\bar{v}(t)$ is not empirically real prior to collapse.

Probability current will flow from the first component to the second, leading to an eventual stochastic hit at time t_{sc} . The result is a state reduction given by

$$U(t \geq t_{sc} > t_0) = \underline{ep}\bar{v}(t)$$

Assume that the neutron moves across the laboratory in a wave packet of finite width, where the launch component $\underline{ep}\bar{v}(t)$ coincides with the neutron as it goes along. At the time t_{sc} of a stochastic hit, the equation $U(t \geq t_0)$ will collapse and a new solution $U(t \geq t_{sc} > t_0)$ will be launched with initial conditions given by the newly realized component $\underline{ep}\bar{v}(t_{sc})$. The decay products $\underline{ep}\bar{v}(t)$ are now empirically real.

Specific values of the electron’s momentum are not stochastically chosen by this reduction. All the possible values of momentum are included in $\underline{ep}\bar{v}(t)$ after the transients associated with $\Delta E \Delta t$ have died out, where Δt begins only after the reduction. These transients do not distract from the instantaneousness of the collapse itself. For the electron’s momentum to be determined in a specific direction away from the decay site, a detector in that direction must be activated. That will require another stochastic hit on the detector.

As in the detector case there are two different kinds of variables associated with the free neutron, those that are affected by a stochastic hit and those that are not. As before, the general way of handling this difference is developed in Appendix I, and its application to this case is given in Appendix II.

Serial Discontinuities

The section on “Particle Capture” shows how the qRules are given their first macroscopic

formulation. The next macroscopic step is to consider a counter C that is activated by a nearby radioactive source.

A series of sm-components $C_0, C_1, C_2, C_3, \dots$ are connected to each other by non-periodic orthogonal quantum jumps. Let C_0 mean that no particles have been captured from the radioactive source, let C_1 mean that one particle has been captured, and let C_2 mean that two particles have been captured, etc.

In standard quantum mechanics a series of captures like this is given by

$$U(t \geq t_0) = C_0(t) + C_1(t) + C_2(t) + C_3(t) + \dots \quad (4)$$

where only C_0 is non-zero at time t_0 . The other components gain amplitude by virtue of probability current flowing from C_0 to C_1 , then to C_2 , and then to C_3 , etc, where the amplitudes of the components form a pulse that moves from left to right in Eq. 4. We do not include the intermediate particle field in this equation, for nothing of significance is changed by imagining that the different counter components interact directly with each other.

The qRules tell a different story. They require that all the current receiving components in Eq. 4 are ready components, so the equation takes the form

$$U(t \geq t_0) = C_0(t) + \underline{C}_1(t) + \underline{C}_2(t) + \underline{C}_3(t) + \dots \quad (5)$$

because each of the ready components satisfies qRule (1), which is to say that each is non-periodic and orthogonal to its predecessor. Probability current will generally flow into more than one of these components at a time, so current might flow simultaneously into \underline{C}_1 and \underline{C}_2 , suggesting that \underline{C}_2 might be stochastically chosen before \underline{C}_1 . That is a very unphysical result because a counter will not record the capture of two particles before it has recorded the captured one particle. The second qRule insures that that *does not happen*. It says that the stochastic trigger will only strike when positive probability current flows into a ready component *from a realized component*. This means that only \underline{C}_1 in Eq. 5 can be stochastically chosen. The qRules therefore guarantee that C_1 is not passed over, and this is an indispensable requirement of any non-Born protocol. Only the first ready component in Eq. 5 is a launch component.

Probability current flowing from C_0 to \underline{C}_1 in Eq. 5 will therefore result in a stochastic hit on \underline{C}_1 at some time t_{sc1} . When that happens we get the first particle capture together with the next ready component in line.

$$U(t \geq t_{sc1} > t_0) = C_1(t) + \underline{C}_2(t) + \dots \quad (6)$$

where $\underline{C}_2(t)$ is zero at t_{sc1} . From this point on, second order components such as $\underline{C}_3(t)$ will not be explicitly shown in a qRule equation because they cannot be launch components. Their presence will be noted by $+\dots$ following the launch component. These second order components are certainly present in the Schrödinger equation but they cannot be stochastically chosen according to qRule (2), so they serve no purpose in a qRule equation.

Following Eq. 6 another stochastic hit at t_{sc2} gives the second particle capture

$$U(t \geq t_{sc2} > t_{sc1} > t_0) = C_2(t) + \underline{C}_3(t) + \dots \quad (7)$$

and so fourth. In Eqs. 5, 6, and 7, the correct sequential order of counter states is guaranteed by qRule (2).

It is characteristic of the sRules (i.e., any Born-interpretation-based theory) that there is only one solution to the Schrödinger equation for the given initial conditions, whereas the qRules provide a separate solution for each discontinuous gap (Eqs. 5, 6, 7, etc.). The launch component will provide the boundary conditions of the next solution; so the emerging value of $\underline{C}_2(t)$ in Eq. 6 defines the initial boundary of the collapsed solution in Eq. 7.

There is no contradiction between the predictions of the qRules and the standard sRules. The qRules are concerned with the probability that a stochastic hit will occur in the next interval dt of time. Opposed to this, the sRules are concerned with the probability distribution of an *ensemble* of states at some finite time T after the apparatus is turned on. These different rules ask different questions having different answers. However, either one of these protocols can be successfully mapped onto the same counter, so there can be no observational contradiction.

Equation 5 applies to *microscopic states* as well, because serial order is just as important in these cases. Atomic states that decay from an initial excited state a_0 will go to the next lower energy state a_1 , and then lower to a_2 without skipping a step – unless that possibility is allowed by the Hamiltonian. If it is not allowed, then a_1 will not be skipped over any more than C_1 in the above macroscopic counter. As in the macroscopic case, qRule (2) is an essential moderator of any serial sequence at the atomic level. Otherwise, the second order component a_2 might be stochastically chosen before a_1 , and that would be unphysical. As it is, the photon between states a_0 and a_1 will be released before the photon between state a_1 and a_2 , and there will be no photon between states a_0 and a_2 . Although the qRules are empirically discovered by investigating macroscopic systems, they can be extended to this microscopic system, thereby supporting the claim that the qRules apply independent of size.

Parallel Discontinuities

Macroscopic parallel branching is also used to check the correctness and generality of the qRules. Imagine two side-by-side counters that are exposed to a radioactive source and are represented by the qRule equation

$$U(t \geq t_0) = C_0(t) + \underline{C}_r(t) + \underline{C}_l(t) + \dots \quad (8)$$

where the initial component $C_0(t)$ means that neither counter has yet captured a particle, $C_r(t)$ means that the counter on the right is the first to make a capture, and $C_l(t)$ means that the counter on the left is the first to make a capture. Let each counter turn off after a single capture. Equation 8 is shown in Fig. 1. Again, we simplify by not including the particle fields.

The ready components $\underline{C}_r(t)$ and $\underline{C}_l(t)$ are initially equal to zero and increase in time. Each one receives probability current from the first component that makes each a contending eigencomponent in this interaction and a candidate for a state reducing stochastic hit. Each is a launch component, where $\underline{C}_r(t)$ is the initial boundary conditions of a launch to the right in Fig. 1, and $\underline{C}_l(t)$ is the initial boundary conditions of a launch to the left. The dashed line in Fig. 1 is a forbidden transition. The final component $\underline{C}_f(t)$ in Fig. 1 is not shown in Eq. 8 because it is a second order transition. Therefore $\underline{C}_f(t)$ cannot be chosen before one of the intermediate components is chosen.

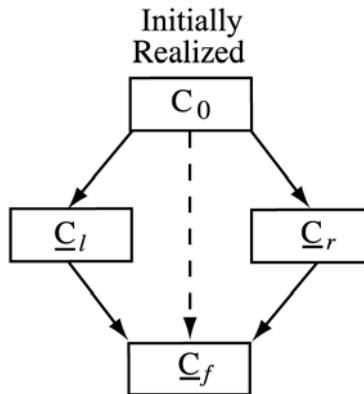


Figure 1. Parallel decay routes

If the launch component \underline{C}_r in Eq. 8 is stochastically chosen at time t_{scr} , the resulting state reduction will be

$$U(t \geq t_{scr} > t_0) = C_r(t) + \underline{C}_f(t)$$

where $\underline{C}_f(t)$ is the launch component to the final state of the system. When it is stochastically chosen at time t_{scf} the system will be in its final state $U(t \geq t_{scf} > t_{scr} > t_0) = C_f(t)$. This sequence will go in a counterclockwise direction if the launch component $\underline{C}_l(t)$ in Eq. 8 is stochastically chosen before $\underline{C}_r(t)$ is chosen.

The second qRule therefore has the effect of forcing these macroscopic counters into either a clockwise or a counterclockwise path in the classical sense. Without the second qRule a second order transition might skip over the intermediate components to score a direct stochastic hit on C_f without one of the intermediate component being definitely involved. This is an unphysical macroscopic behavior. Here again we see the indispensability of qRule (2) if macroscopic objects are to be quantum mechanically described with a non-Born protocol.

The same will be true of *microscopic* parallel systems. Any “non-periodic orthogonal quantum jump” imposes an abrupt and lasting change of a distinctive kind in some part of the universe – even in a microscopic case. For instance, let Fig. 1 represent two alternative routes from a high-energy atomic state a_0 to the ground state a_f , where the intermediate components do not interact with each other. The two photons that are released along each path will leave an indelible record that will be different for each path (assuming non-degeneracy); so if the two photons associated with the clockwise path are found in the wider universe, then the clockwise path must have been stochastically chosen. It is not possible for *all four* photons to be found in a single trial. It will be either the two photons from the left or the two from the right. The released photons are the abrupt and lasting change referred to above, and their distinctive characteristics along each path removes any doubt as to which path is finally traversed.

More generally for any microscopic/macroscopic – series/parallel combination of paths, any single path segment that follows and precedes a non-periodic orthogonal quantum jump will be correctly described by a qRule equation.

Add an Observer

When an observer is added to the system it is macroscopic, so the results of this section

may be considered a further check on the correctness of the qRules.

Imagine that an observer witnesses the capture of a particle in Eq. 2. The resulting qRule equation would then be

$$U(t \geq t_0) = pd_0B_0(t) + \underline{d}_1B_1(t) \quad (9)$$

where B_0 is the brain of a conscious observer witnessing the detector d_0 in its ground state, and B_1 is the brain of the observer witnessing the detector d_1 in its capture state. As before, it is not necessary to underline both states in the ready component. Because B_1 is in the ready component it is not yet empirically realized, so it cannot be a conscious brain. Until there is a stochastic hit on \underline{d}_1B_1 the observer is only conscious of the detector in its ground state through the conscious state B_0 .

Probability current flowing from the first to the second component in Eq. 9 may produce a stochastic hit resulting in

$$U(t \geq t_{sc} > t_0) = d_1B_1(t) \quad (10)$$

so the brain state B_1 becomes part of a realized component at time t_{sc} , which means that the observer becomes consciously aware of the capture at that time.

Equation 9 would also be correct in standard quantum mechanics that is based on the Born rule and the Schrödinger equation alone. However, in standard theory the second component in Eq. 9 would have the same empirical significance as the first. When applied to an individual trial (i.e., not an ensemble of trials), this produces a paradoxical situation reminiscent of Schrödinger's cat experiment. The brain of the observer would then be seen to be consciously observing the detector in both its d_0 and its d_1 state *at the same time*.

This difficulty is related to the fact that standard theory regards Eq. 9 as a complete dynamic process, whereas the qRules include both Eq. 9 and Eq. 10 in the process. Typically, standard theory employs only one set of boundary conditions (i.e., the initial conditions), whereas the qRules employ multiple boundary conditions – two in this case. Every measurement introduces new boundaries, so the qRules supplement the initial conditions of Eq. 9 with new boundary information to the effect that the particle has been captured – giving the initial conditions of Eq. 10. Standard theory fails to ground the Schrödinger equation in new boundaries when they occur, whereas qRule theory assimilates new boundary information every time there is a collapse of the wave.

It is possible to refine the account described in Eqs. 9 and 10. To this end, the initial detector d_0 is understood to mean the laboratory apparatus *plus* the physiology of the observer up to that part of the brain that records conscious experiences. The detector therefore includes all the brain parts that are engaged in image processing prior to conscious experience, and the brain state B is confined to the part of the cerebral physiology (i.e., the pre-frontal cortex) that supports conscious experiences.

We then write Eq. 9 in the form

$$U(t \geq t_0) = pd_0B_0(t) + \underline{d}_{w1}B_0(t) \quad (11)$$

where d_{w1} is the detector at the moment of capture when only its window registers the presence of the particle. The associated unconscious ready brain state in $\underline{d}_{w1}B_0(t)$ will still be 'looking at' the ground state detector because the signal has not as yet traveled through the detector to tell the higher brain what has happened. When the launch component in Eq. 11 is stochastically chosen at time t_{sc} , we will have

$$U(t \geq t_{sc} > t_0) = d_{w1}B_0(t) \rightarrow d_{i1}B_0(t) \rightarrow d_{f1}B_1(t) \quad (12)$$

where the arrows represent a continuous classical progression of the signal through the detector. The three terms in Eq. 12 represent a single realized sm-component that evolves continuously in time under the Schrödinger equation. State d_{i1} is the detector when the signal has reached the half-way mark, and d_{f1} is the detector when the signal has finally reached the neo-cortex, at which time the brain B_1 will be conscious of the detector in its capture state.

It may appear that we have revived a cat-like paradox because Eq. 12 contains both the conscious pre-capture brain state B_0 and the conscious post-capture state B_1 . However, the equation does not include these two states *at the same time*, so a paradox is avoided. The qRules therefore allow a secondary observer to be admitted to the system without a cat-like ambiguity of the kind that concerned Schrödinger. But more than that, the qRules allow the primary observer to include himself in the system. He has only to imagine that it is his brain that is in contact with the detector, and the Schrödinger dynamics will predict his experience. In this respect, the relationship of the primary observer to the system under the qRules is similar to that in classical physics.

Equation 12 shows that the brain goes from one state of consciousness to another by a continuous classical process. This change is not a quantum jump as suggested by the courser analysis in Eqs. 9 and 10. However, an even more refined description is required because Eqs. 11 and 12 are still not quite right. A fully correct account is possible only when the process given in Appendix I is applied to this case. The ‘observed detector’ then follows a pattern similar to that of the ‘detector capture’ and the ‘free neutron decay’ that are described in Appendix II.

Multiple Parallel Sequences

Construct a network of 10 macroscopic counters and their associated radioactive sources, where the source associated with the initial state CB_0 selects one of the eigenstates CB_1 or CB_2 or CB_3 . The counter C is witnessed by a brain state B , where the subscript on B denotes the counter that is seen by the brain. After the first stochastic choice that carries the system from the first to the second row of Fig. 2, there is a second choice that carries the system to the third row.

There are six possible sequences in this diagram. In the many-world universe of Everett these branches (or sequences) all run together in a single solution of the Schrödinger equation, so there is only one set of initial boundary conditions. The observer who inhabits one of these branches cannot be aware of his own alter-ego in another branch, for that would disqualify the idea. Everett showed that once begun, one of these sequences will proceed without any further involvement with any other sequence. That means that the observer on one branch of this system will not be aware of his alter-ego on another branch. The branches therefore proceed independent of one another, even though they are all part of a single solution. As before, the particle field is not included in the analysis.

The qRules do not run all these solutions together. They say instead that each stochastic choice in Fig. 2 is the occasion of a collapse of the wave and the launch of a new solution of Schrödinger’s equation. Each of the six possible sequences consists of two collapses following the initial state CB_0 . There will therefore be three separate equations that carry the initial state into a final state. For the sequence CB_0, CB_1, CB_{1b} , those equations are

$$U(t \geq t_0) = CB_0(t) + \underline{CB}_1(t) + \underline{CB}_2(t) + \underline{CB}_3(t) + \dots$$

$$U(t \geq t_{sc1} > t_0) = CB_1(t) + \underline{CB}_{1a}(t) + \underline{CB}_{1b}(t)$$

$$U(t \geq t_{sc2} > t_{sc1} > t_0) = CB_{1b}(t)$$

where the ready components in each equation are initially zero. Second order components (i.e., ready components that are not launch components) are not explicitly shown in the first equation.

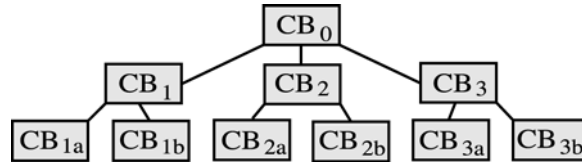


Figure 2: Six possible sequences

Although this example is illustrated with macroscopic instruments, it would work as well with a microscopic array of atomic states where there can be no observers. This again is because every stochastic hit leaves a mark on the wider universe that indelibly records the choice. In this case, the mark takes the form of an emitted photon or other happening that is recorded in the ‘memory’ of the universe, much as the memory of each alter-ego is irreversibly and independently affected in Everett’s theory.

Compton Scattering

The Compton scattering of a photon off of an electron center represents an entanglement that is surely non-periodic. It also appears to represent a quantum discontinuity, for the initial momentum is carried into a scattered momentum in a way that involves Planck’s constant. However, this is an asymptotic discontinuity. There are no orthogonal quantum jumps near the scattering center, so there is no ready component and no collapse of the wave. The qRule equation is given by $U = \gamma e = \text{constant}$, where γ is the incoming photon and e is the electron. Although the two parts of U undergo dramatic continuous and correlated change at the wave function level, this change has no effect on the magnitude of the trans-representational sm-component. The qRule equation is therefore constant. The same may be said of Bragg scattering.

Atomic Absorption and Emission

Applying this scheme to the case of atomic absorption and emission, the atom in its ground state interacts with a laser field γ_N containing N photons. These photons have a frequency 0-1, where 0 refers to the ground state a_0 , and 1 refers to the excited state a_1 . The qRule equation is then

$$U(t \geq t_0) = \gamma_N a_0 \Leftrightarrow \gamma_{N-1} a_1 + \gamma_{N-1} \underline{a_0} \otimes \gamma \quad (13)$$

where only the first component is non-zero at time t_0 . Each component in this equation is a function of time, but that is not specifically shown in order to simplify the notation. The double arrow (\Leftrightarrow) represents a periodic Rabi oscillation that begins at t_0 . When the atom is in the excited state a_1 a spontaneous emission to ground becomes a possibility, represented here by the ready component. That emission is non-periodic and the resulting component $\gamma_{N-1} \underline{a_0} \otimes \gamma$ is an orthogonal quantum jump from $\gamma_{N-1} a_1$ because a_1 is orthogonal to a_0 . When the ready component

in Eq. 13 is stochastically chosen the atom goes to ground emitting a photon γ that came to it from the laser beam. The symbol \otimes indicates the independence of the released photon from the atom. It is true that the surviving component $\gamma_{N-1}\underline{a}_0\otimes\gamma$ will undergo transients associated with $\Delta E\Delta T$ immediately after collapse, but these will rapidly diminish and will not distract from the instantaneousness of the collapse itself.

If the atom begins in the excited state and is exposed to a laser beam, we get

$$U(t \geq t_0) = \gamma_N a_1 \Leftrightarrow \gamma_{N+1} a_0 + \gamma_N \underline{a}_0 \otimes \gamma \quad (14)$$

where again, only the first component is non-zero at t_0 . A stimulated emission oscillation begins immediately, and a spontaneous emission from the excited state is represented by the ready component. Except for the fact that Eq. 14 is shown to have one more photon than Eq. 13, the two equations are identical. It cannot matter if the oscillation begins in a_0 or in a_1 .

A Laser

Given a four-level atom with a ground state a_0 and three excited states a_1, a_2, a_3 of increasing energy. It is immersed in a laser field of N photons, each with an energy connecting levels a_1 and a_2 . The atom is initially pumped into the short-lived state a_3 and quickly drops to a_2 with an energy loss involving some dissipative process that may be molecular collisions, or possibly the spontaneous (i.e., non-periodic) emission of a 3–2 photon.

$$U(t \geq t_0) = \gamma_N a_3 + \gamma_N \underline{a}_2 \otimes e_x$$

where the second component is zero at t_0 and increases in time. The brief Rabi oscillation in this equation is not shown; and again, the explicit time dependence of each component is not shown. The symbol e_x represents a dispersive process that absorbs the energy difference. With a stochastic hit on the ready component in this equation at time t_{sc1} , the system becomes

$$\begin{aligned} U(t \geq t_{sc1} > t_0) = & \gamma_N a_2 \otimes e_x \Leftrightarrow \gamma_{N+1} a_1 \otimes e_x \\ & + \gamma_N \underline{a}_1 \otimes e_x \otimes \gamma \quad (\text{metastable}) \\ & + \gamma_{N+1} \underline{a}_0 \otimes e_x \otimes e_{xx} \quad (\text{short-lived}) \end{aligned}$$

where only the first component is non-zero at t_{sc1} . The double arrow again represents a Rabi oscillation. The metastable launch component in the second row is a long-lived spontaneous photon emission coming off of a_2 in the first row. The symbol e_{xx} in the short-lived launch component (third row) represents that part of the environment that irreversibly takes up the energy difference between a_1 in the first row and a_0 in the third row. The short-lived decay product is more likely to be stochastically chosen than the metastable one, so after a second hit at time t_{sc2} we have preferentially

$$U(t \geq t_{sc2} > t_{sc1} > t_0) = \gamma_{N+1} a_0 \otimes e_x \otimes e_{xx}$$

Comparing the original state $\gamma_N a_3$ with the final state $\gamma_{N+1} a_0 \otimes e_x \otimes e_{xx}$, it is clear that the energy difference between a_3 and a_0 is the energy of the new photon in the laser beam plus the two dissipative processes e_x and e_{xx} . This cycle is repeated many times resulting in pumping many new photons into the laser beam. Evidently each photon pumped into the beam involves three qRule equations and requires two stochastic hits – i.e., two wave collapses associated with two non-unitary processes. I do not call these “measurements” because I think it is best to reserve that word for non-unitary processes that involve macroscopic instruments.

Localization

An ‘object localization’ property is essential to physics if macroscopic objects are to be limited in space as we commonly experience with them. This property does not follow from the Schrödinger equation by itself, for objects subject only to that equation will expand forever due to their uncertainty in momentum. This may not seem to be a problem in a universe that consists of scientific instruments that are already well localized. But our universe evolved from one that was not well localized. Go back to the time of recombination some 300 thousand years after the big bang when the only atomic structures are hydrogen and helium. These atoms must have had a very large uncertainty of position at that time; and under the influence of Schrödinger’s equation alone, subsequent evolution created more complex atoms whose uncertainty of position was at least that of the original hydrogen and helium atoms. This happened because the Schrödinger equation supports correlations but not contractions of the wave function; so it will not (by itself) reduce an existing uncertainty of location. Evolution then produced macroscopic objects such as rocks that followed the same pattern. That is, under the influence of the Schrödinger equation alone, correlations produced macroscopic rocks with an uncertainty of location that was at least that of the atoms that went into their construction. *The Schrödinger equation can support a macroscopic location superposition just as easily as it can support a microscopic location superposition*, and it will do so unless there is a collapse mechanism that opposes it. The only reason we don’t now experience rock superpositions left over from the time of recombination is that contemporary rocks must have undergone a great many wave contractions over the eons. These contractions must have occurred without the help of pre-existing localized macroscopic objects, for such objects did not exist 300 thousand years after the big bang. Foundation theory must therefore include auxiliary rules to the Schrödinger equation that provide for a collapse mechanism.

The qRules satisfy this requirement. They provide for the frequent occurrence of state reductions that apply to microscopic objects, and through correlations, to macroscopic objects as well. Instead of showing this for a solid rock, we will illustrate the point by showing how the qRules affect state reductions of free atoms like the original hydrogen or helium atoms, causing them to be well localized in spite of the previous expansion of their atomic parts. Similar arguments can be generalized to include rocks.

Let a photon raise an atom to an excited state, after which the atom drops down again by spontaneously emitting a photon. The incoming photon is assumed to be spread out widely over space. The atom is also assumed to be spread out over space by an amount that exceeds its *minimum volume*. This is defined to be the smallest volume that the atom can occupy consistent with its uncertainty of momentum. The atom in Fig. 3 (shaded area) is assumed to have spread far beyond this volume before it interacts with the photon. As the incoming photon passes over the enlarged atom, the scattered radiation will appear as many photons that originate from different parts of the atom’s extended volume as shown in Fig. 3 – these are the small wavelets in the figure.

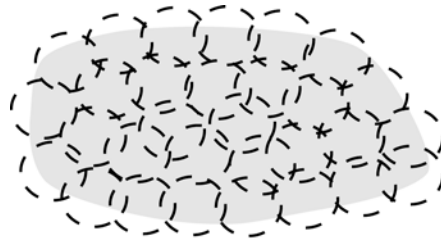


Figure 3: Small wavelets

The correlations between the nucleus of the atom and its orbiting electrons must be preserved, even though the atom is spread out over a much larger volume. That is, the smaller dimensions of the minimal volume atom must be unchanged during its expansion, so the potential energy of the orbiting electrons is unchanged. The atom could not otherwise act as the center of a ‘characteristic’ photon emission. This means that the incident photon will engage the compact atom throughout every part of the enlarged volume.

Equation 13 describes how an atom will respond to a laser field of N photons. The same will be true of the atom in Fig. 3, except that the spontaneous photon emission part of that equation will be the sum of the probabilities of emissions coming from different locations within the extended atom. The qRule equation for the total process is therefore given by

$$U(t \geq t_0) = \gamma_N a_0 \Leftrightarrow \gamma_{N-1} a_1 + \frac{\lim}{n \rightarrow \infty} \sum_n \gamma_{N-1} a_{0n} \otimes \gamma_n$$

where \sum_n is a sum over all the ways that the atom can spontaneously emit a photon (i.e., all the wavelets in the figure), and a_{0n} refers to each associated minimum volume atom. As the sum over n goes to infinity, the probability current flowing into each term in the summation goes to zero in such a way as to preserve the total square modulus.

Notice that the wavelets in Fig. 3 are confined to ready components so they are physically unreal. If a stochastic hit occurs at time t_{sc} on the minimum volume atom a_{0sc} , the equation becomes

$$U(t \geq t_{sc} > t_0) = \gamma_{N-1} a_{0sc} \otimes \gamma_{sc}$$

So the atom is *reduced to its minimum volume* in this interaction. This may be different from the ‘initial’ minimum volume because $\Delta \mathbf{p}$ of the atom might have changed during its interaction with the radiation field.

It is important that the qRules provide a mechanism for a reduction of this kind without introducing artificial notions such as previously localized macroscopic instruments. It is important that the rules provide an automatic *contraction* mechanism to counteract the automatic *expansion* mechanism of Schrödinger’s equation.

If the different parts of the extended atom interact ‘differently’ with other objects prior to the above reduction, than those objects will also experience a reduction through the correlations that have been established. There may be many ways in which a reduction might take place [8]. This example alone shows how the qRules insure that reductions are quite common.

Experimental Test

The GRW/CSL theory predicts the existence of a physical constant λ that governs the rate of collapse of the wave function (Ref. 7). This constant is supposedly a very small number whose existence has not yet been experimentally confirmed, but is confirmable in principle. There is no such constant in qRule theory according to which each individual collapse is instantaneous. There are other differences. For instance, the frequency of qRule wave reductions of a small metallic disk (on the order of $2 \cdot 10^{-5}$ cm radius) at low temperature and pressure depends on the *collision frequency* with which atmospheric molecules hit the disk. The resulting temperature and/or pressure dependence of the reduction rate in a metallic disk is a distinguishing experimental feature of qRule theory. It is certainly not a feature of the GRW/SCL theory. So even though probabilities or cross sections cannot be directly calculated from qRule equations, this example shows that there are circumstances in which the qRules allow us to make definite predictions that set them apart from the predictions of other theories [9].

Rather than demonstrate this dependence with a disk, it is simpler to imagine the collapse mechanism with a small sphere.

A small sphere of radius $r_0 \approx 10^{-5}$ cm is solid aluminum or gold. Imagine that it has expanded to five times that radius at a time t_0 as a result of the uncertainty of its momentum. This is shown in Fig. 4a where a number of small dashed spheres representing the minimum volume sphere are circumscribed by a large dashed sphere representing its uncertainty of position. An incoming molecule shown as a black dot in Fig. 4b penetrates the extended radius, engaging the sphere at various points in *faux* collisions (defined in Appendix I). These are

collisions that occur in a ready component of the qRule equation prior to a stochastic hit, so they have no empirical reality even though their wave function goes into the Schrödinger equation. Only two faux collisions are shown in Fig. 4b (dashed lines), although there is a continuum of collisions like this prior to the stochastic hit. The third collision pictured in Fig. 4b (solid lines) is assumed to occur at the time of a stochastic hit, so it is a *realized* collision. Each of these collisions is non-periodic.

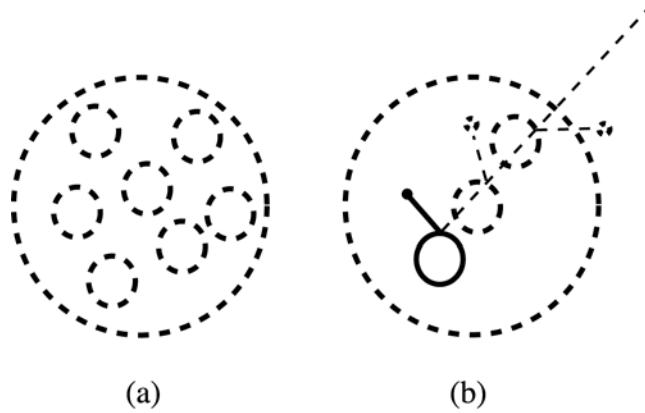


Figure 1: Uncertainty of position of sphere

If the collisions in Fig. 4b are also continuous like Compton scatterings there will be no collapse of the wave. For a collapse to occur there must also be an orthogonal quantum jump. A change in the rotational level of the disk will generally provide the required jump. A diatomic molecule at 4.2°K may also provide rotational levels for this purpose. Either way, it is overwhelmingly likely that the interaction gap will be orthogonal. This together with non-periodicity satisfies the conditions for a state reduction, giving us still another localization mechanism.

Following the process described in Appendix I, the qRule equation after the interaction is given by

$$U(t \geq t_0) = sm(t) + \int_0^{a(t-t_0)} \underline{s}'m'(t, \tau) d\tau$$

where s is the initial sphere and m is the initial incoming molecule. The sphere after collision is given by s' and the molecule is given by m' . Each differential contribution to the integrand is a ready component describing a faux collision (defined in Appendix I), but only the first is shown there to be a launch component. This equation can therefore be written

$$U(t \geq t_0) = sm(t) + \underline{s}'m'(t, 0) d\tau + \dots$$

Again following Appendix I, a stochastic hit at time t_{sc} yields

$$U(t = t_{sc} > t_0) = s'm'(t_{sc}, 0) = s'm'(t_{sc})$$

The collision dependence of this reduction presents an opportunity for *an experimental test of the theory* [10]. An experiment that uses a disk rather than a sphere would provide a measurement opportunity of this kind (Ref. 9). No other foundation theory predicts a result that is so collision dependent.

Other Applications

The qRules give good results when applied to *two* observers witnessing the capture of a particle by a detector, or when only one observer is present for only a *part* of the interaction time [11].

In a separate paper the Schrödinger cat experiment is examined in all of its variations [12]. In one version the cat is initially conscious and is made unconscious by a mechanical device that is initiated by a radioactive emission. In another version the cat is initially unconscious and is made conscious by an alarm clock that is set off by a radioactive emission. In still another version, the cat is awakened by a natural internal alarm (such as hunger) that is in competition with an external mechanical alarm. In all these cases, the qRules are shown to accurately and unambiguously predict the expected conscious experience of the cat at any moment of time. And finally, an external observer is assumed to open the box containing the cat at any time during any one of these experiments; and when that happens, his experience of the cat's condition is correctly predicted by the qRules. The examples in Refs. 11 and 12 use the nRules, but the consequences are the same as they would be using the qRules.

The qRules are of great heuristic value inasmuch they make sense of processes that are not otherwise understandable. The shelving phenomenon of quantum optics originally observed by Dehmelt is an example [13]. When oscillations between fluorescent periods and dark periods are represented by a qRule equation, the 'causal' question raised by Shimony is answered [14]. That equation looks to the Schrödinger solution for its formulation, for qRule equations cannot determine the cross section of a process or allow one to calculate its probability. However they do establish the consistency of the shelving process with the same reduction rules that govern everything else [15]. Again, the argument in Ref 15 uses the nRules as its axiomatic basis, but qRules produce the same result.

The qRules are relativistically covariant because all possible representations have been integrated out, including all possible coordinate representations. However, the relativistic collapse of a quantum mechanical system presents problems that cannot be decided by either standard quantum mechanics or relativity alone. A separate collapse theory is necessary to address the unresolved difficulties. The qRule theory does this in a completely satisfactory way, as will be shown in a subsequent paper.

Prospects

The qRules are equivalent to any other current foundation theory of quantum mechanics in the sense that there is no current experimental evidence to disqualify any one of them. However, there are experimental prospects. The experiment described in the "Experimental Test" section is intended to test the GRW/CSL theory, but it also provides an opportunity to confirm predictions of the qRule theory that would exclude all other current theories. It predicts a collision state reduction with a temperature and pressure dependence that is unique to the theory (Ref. 10).

Appendix I

Let a non-periodic interaction in a system with coordinates x_1, x_2, x_3, \dots give rise to a second component that is orthogonal to the first in the equation

$$\Psi(x_1, x_2, x_3, \dots, t \geq t_0) = \psi_0(x_1, x_2, x_3, \dots, t) + \int_0^{a(t-t_0)} \psi_1(x_1, x_2, x_3, \dots, t, \tau) d\tau \quad (15)$$

where a is a constant with units of inverse time. Some of the variables in this integral evolve in time t independent of a stochastic choice, and others vary with the unitless parameter τ indicating that they are affected by the stochastic choice. At every moment of time the Schrödinger equation initiates a 'possible' stochastic choice that the equation carries through to completion as though it had actually occurred. The above integral is a sum of all these possible evolutions, where an initiating quantum jump is designated at each moment by the setting $\tau = 0$.

The integral in Eq. 15 is an array of differentially small components that begins by setting $\tau = 0$ at each moment in time. Starting at time t_0 and skipping to finitely separated times t_1, t_2, t_3 , etc., the array is

$$t_0 : \boldsymbol{\psi}_1(\mathbf{x}.., t_0, \mathbf{0})d\boldsymbol{\tau}$$

$$t_1 : \psi_1(x.., t_1, 0)d\tau + \boldsymbol{\psi}_1(\mathbf{x}.., t_1, \boldsymbol{\tau}_1)d\boldsymbol{\tau}$$

$$t_2 : \psi_1(x.., t_2, 0)d\tau + \psi_1(x.., t_2, \tau_1)d\tau + \boldsymbol{\psi}_1(\mathbf{x}.., t_2, \boldsymbol{\tau}_2)d\boldsymbol{\tau}$$

$$t_3 : \psi_1(x.., t_3, 0)d\tau + \psi_1(x.., t_3, \tau_1)d\tau + \psi_1(x.., t_3, \tau_2)d\tau + \boldsymbol{\psi}_1(\mathbf{x}.., t_3, \boldsymbol{\tau}_3)d\boldsymbol{\tau}$$

$$t_4 : \psi_1(x.., t_4, 0)d\tau + \psi_1(x.., t_4, \tau_1)d\tau + \psi_1(x.., t_4, \tau_2)d\tau + \psi_1(x.., t_4, \tau_3)d\tau + \boldsymbol{\psi}_1(\mathbf{x}.., t_4, \boldsymbol{\tau}_4)d\boldsymbol{\tau}$$

$$t_5 : \text{etc.}$$

where the intervals between t_0, t_1 , and t_2 etc are really a continuum of infinitesimal intervals in the variable t .

The initial component $\psi_1(x.., t_0, 0)d\tau$ at time t_0 is advanced by the Schrödinger equation along the *diagonal* of bold face components in the array. This diagonal shows the evolution of the process that is begun at t_0 and proceeds independent of other processes that are initiated at other times. The integral at time t_3 is equal to the sum of components along the horizontal at t_3 . A new process begins at each moment of time because the first component ψ_0 in Eq. 15 continuously feeds current into the second component.

The two components in Eq. 15 are orthogonal, so when the square modulus is integrated over x_1, x_2, x_3, \dots the cross term equals zero. The square modulus of the second component by itself is the ready component given by

$$\underline{u}_1(t) = \int_0^{a(t-t_0)} \underline{u}_1(t, \tau) d\tau \quad (16)$$

$$\text{where} \quad \underline{u}_1(t, \tau) = \int dx_1, dx_2, dx_3 \dots \int_0^{a(t-t_0)} \psi_1^*(x_1, x_2, x_3, t, \tau) \psi_1(x_1, x_2, x_3, t, \tau) d\tau'$$

The integral in this equation is also an array of differentially small components that begins by setting $\tau = 0$ at each moment in time. Starting at time t_0 as above and skipping to finitely separated times t_1, t_2, t_3 , etc., the new array is

$$\begin{aligned}
t_0 &: \underline{u}_1(t_0, \mathbf{0})d\tau \\
t_1 &: \underline{u}_1(t_1, 0)d\tau + \underline{u}_1(t_1, \tau_1)d\tau \\
t_2 &: \underline{u}_1(t_2, 0)d\tau + \underline{u}_1(t_2, \tau_1)d\tau + \underline{u}_1(t_2, \tau_2)d\tau \\
t_3 &: \underline{u}_1(t_3, 0)d\tau + \underline{u}_1(t_3, \tau_1)d\tau + \underline{u}_1(t_3, \tau_2)d\tau + \underline{u}_1(t_3, \tau_3)d\tau \\
t_4 &: \underline{u}_1(t_4, 0)d\tau + \underline{u}_1(t_4, \tau_1)d\tau + \underline{u}_1(t_4, \tau_2)d\tau + \underline{u}_1(t_4, \tau_3)d\tau + \underline{u}_1(t_4, \tau_4)d\tau \\
t_5 &: \text{etc.}
\end{aligned} \tag{17}$$

where each of these is an sm-component that is complete.

As before, all the components following $\underline{u}_1(t_0, 0)d\tau$ that go down the bold faced diagonal are advanced along that line by the dynamic principle. They represent the time development of a *single* continuous sm-component that begins with the interaction at time t_0 . Although the component $\underline{u}_1(t_3, \tau_1)d\tau$ is included at the 4th horizontal level in Eq. 17, the diagonal that includes it follows from a process that begin at time t_2 .

Every component in the above qRule array is a ready sm-component, so none of the processes described in the integral of Eq. 16 are empirically real. That integral introduces *faux processes* as a function of τ that have no empirical significance. Because a component along any diagonal is part of the single ‘diagonal component’, $\underline{u}_1(t_3, \tau_1)d\tau$ is understood to be the value of the third diagonal (above) at time t_3 . Each diagonal is at all times orthogonal to the predecessor $u_0(t)$ (not shown in Eq. 17) that initiated the process. Furthermore, only the first component along any horizontal line of the array is a launch component, for only it receives probability current directly from the realized component $u_0(t)$.

Therefore, only the first component in the array can be stochastically chosen. If that happens at time $t_{sc} = t_5$ in the above array, then following t_3 the array will become

$$\begin{aligned}
t_4 &: \underline{u}_1(t_4, 0)d\tau + \underline{u}_1(t_4, \tau_1)d\tau + \underline{u}_1(t_4, \tau_2)d\tau + \underline{u}_1(t_4, \tau_3)d\tau + \underline{u}_1(t_4, \tau_4)d\tau \\
t_5 &: u_1(t_5, 0)d\tau \\
&\quad + u_1(t_6, \tau_1)d\tau \\
&\quad\quad + u_1(t_7, \tau_2)d\tau \\
&\quad\quad\quad + \text{etc.}
\end{aligned}$$

where the other processes are eliminated by the reduction. No new processes are begun after t_5 because the realized component $u_0(t)$ that fed the array is also reduced to zero. The unrealized diagonals in this equation correspond to the many-world possibilities of Everett that a collapse theory eliminates.

Therefore, the total square modulus of Eq. 15 can be written in form

$$U(t \geq t_0) = u_0(t) + \underline{u}_1(t, 0)d\tau + \dots \tag{18}$$

and this results in a reduced component at time t_{sc} equal to

$$U(t = t_{sc} > t_0) = u_1(t_{sc}, 0)d\tau$$

that has a magnitude Jdt . It is required by qRule (3) that the surviving realized component has a finite magnitude. This can be arranged by dividing by $d\tau$, giving

$$U(t = t_{sc} \geq t_0) = u_1(t_{sc}) \tag{19}$$

that now has a magnitude $Jdt/d\tau$. Since $dt/d\tau$ is arbitrary, the magnitude of $u(t_{sc})$ is arbitrary but finite as required. The variable τ is here replaced by $a(t - t_{sc})$ in the equation $u(t)$ for $t \geq t_{sc}$.

The consequences of Eqs. 18 and 19 are illustrated in Appendix II dealing with a detector capture and a neutron decay.

Appendix II

1. A particle capture

The launch component in Eq. 2 develops in two different ways: One is dependent on time t and the other is dependent on the unitless parameter τ in Eq. 15. Imagine that the detector contains a clock that is set to read t_0 at the beginning of the experiment and ticks continuously thereafter. Its behavior in the launch component will proceed without regard to the possibility of capture, so its variables will depend on the time t . But the ionic cascade that is initiated when the particle enters the detector's window behaves differently. The time of that event is uncertain before there has been a stochastic hit, so the wave equation will include the "possibility" of a cascade beginning at each moment of time after the interaction begins. These are faux cascades because they are not empirically real. They exist only in the ready components of the integral, where each is initiated with the setting $\tau = 0$. The first integrand $\underline{u}(t_1, 0)$ at time t_1 in Eq. 15 is equal to $\underline{d}_1(t_1, 0)$ and represents the possibility that a faux cascade begins at time t_1 when the clock reads t_1 . The total integral is the sum of all the possibilities up to that time. A stochastic hit at time t_{sc} collapses the integral, preserving only the cascade with the initial conditions given by

$$u(t_{sc}, 0) = d_1(t_{sc}, 0) = d_1(t_{sc}).$$

as in Eq. 3 with $t = t_{sc}$.

2. A free neutron decay

Since the wave packet of the launch component moves across the laboratory following the wave packet of the neutron, the variables of this motion are a function of t in Eq. 15 and evolve independent of the possibility of a stochastic hit.

The time of decay is uncertain before there has been a stochastic hit, so the wave equation will include the possibility of a decay beginning at each moment of time after the neutron begins its flight. Consequently, the neutron will be spewing out faux decay particles in all directions as it moves across the laboratory. Each of these decays is keyed to the parameter τ in Eq. 15, where $\tau = 0$ signifies its beginning of a faux decay. The first integrand $\underline{u}(t_1, 0)$ at time t_1 in Eq. 15 is equal to $\underline{ep\bar{v}}(t_1, 0)$ and represents the possibility that a faux decay begins at time t_1 with $\tau = 0$. The total integral is the sum of all the possibilities up to that time. These decay particles will not be empirically real until time t_{sc} at which time a stochastic hit collapses the integral, realizing the cascade with the initial conditions given by

$$u(t_{sc}, 0) = ep\bar{v}(t_{sc}, 0) = ep\bar{v}(t_{sc})$$

References

References 1, 2, 8, 10, 11 and 14 use four nRules instead of the current three qRules. Apart from a different axiomatic basis, we now envision a different rationale for a qRule collapse than is found in these references. Other than that, the equations and conclusions are the same for the qRules as they are for the nRules.

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