Quantum brains: The oRules

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Quantum mechanics traditionally places the observer 'outside' of the system being studied and employs the Born interpretation. In this presentation and related papers the observer is placed 'inside' the system. To accomplish this, special rules are required to engage and interpret the Schrödinger solutions in individual measurements. The rules in this presentation (called the oRules) do not include the Born rule that connects probability with square modulus. It is required that the rules allow conscious observers to exist inside the system without empirical ambiguity – reflecting our own unambiguous experience in the universe. This requirement is satisfied by the oRules. These rules are restricted to observer measurements, so state reduction can only occur when an observer is present.

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I. INTRODUCTION

Standard quantum mechanics is based on an *epistemological* model that places the observer 'outside' the system being investigated. The observer there performs laboratory operations and/or chooses mathematical operators in order to obtain information about the system. The large OP in Fig. 1 represents these operations. The epistemological observer always uses the *Born rule* to interpret solutions of Schrödinger's equation.

The model used in this paper is an ontological one (see Fig. 2). Anything and anybody may be considered 'inside' this system (as in classical physics), including all *conscious* observers. Measurement in an ontological model is not described in terms of operators or operations applied externally. Instead, a measurement is described as an interaction of all the physical objects involved. If the sub-system being studied is given by S, and the detector is D, then the measurement interaction is given by $\Phi = SD$. If an observer is also looking at the detector, then $\Phi = SDB$, where B is the brain state of the observer.

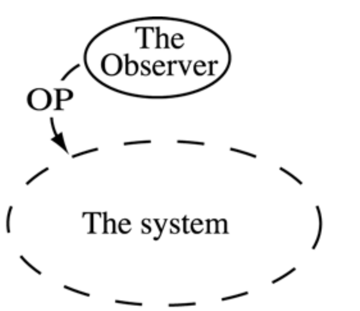

FIG. 1: Epistemological Model

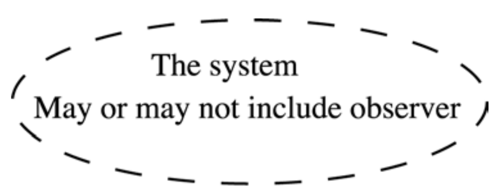

FIG. 2: Ontological Model

In some circumstances the Born rule is valid for an ontological observer, but it is not generally valid; so special rules must be devised for this case. In a later section we will explain why the Born rule is not generally compatible with an ontological model. There are at least two possible ontologies (defined by the two different sets of rules) replacing the Born rule. Both are quantum mechanical ontologies that are distinctly different from classical ontology as will be seen below.

There are three characteristic features of an ontological model. (1) An observed measurement is given by $\Phi = SDB$, (2) The observer makes continuous observations, and (3) It rejects the Born rule.

II. ANOTHER RULE- SET

The two rule-sets that have so far been developed are:

The oRules (1-4) described in this presentation consist of four separate rules that allow a state reduction only when an observer is present.[1, 2] These rules reflect the thinking of Wigner and von Neumann by placing the conscious observer at the center of any real measurement.[3. 4] A real measurement is one that establishes a new *boundary condition* on the Schrödinger equation by making a stochastic choice that changes the solution of the equation.

The nRules (1-4) also consist of four separate rules that place the conscious observer inside the system, but they allow an objective measurement to occur because the presence of the conscious observer is not here required.[5] A new boundary condition (resulting in a collapse of the state) can be achieved in the nRules with the interaction $\Phi = SD$ without the benefit of an observer. The detector alone can do the job.

The Born rule is not included in either of the rule-sets as has been said. In both cases, probability is introduced through the notion of *probability current*.

Neither one of these rule-sets is a ‘theory’. I make no attempt to understand *why* the rules work, but strive only to insure that they do work. They work in the sense of accurately and unambiguously describing the empirical experience of a conscious observer who interacts with a measuring device. The resulting ontology is like an empirical formula that awaits a theoretical explanation. Each rule-set may be compared to the rules of atomic spectra before there was an atomic theory to make sense of them. Inasmuch as the rule-sets are macroscopic and make no reference to neurological configurations, they may also be compared to the rules of thermodynamics that make no reference to molecular motion.

In the end I do not choose between the nRules and the oRules. They cannot both be correct and it might be that neither is correct. There might be other ontological models that are more satisfactory.

III. THE INTERACTION

Let a free particle ψ passes over a detector d beginning at time t_0. The detector may or may not capture the particle.

$$\Phi(t \geq t_0) = \psi(t)d_0 + d_1(t) \tag{1}$$

where the second component is zero at t_0 and increases in time. Let $\Phi(t \geq t_0)$ be in a representation whose components can be grouped so that the first component includes the detector d_0 in its ground state prior to capture, and the second component includes the detector d_1 in its capture state. There is then a clear discontinuity or "quantum jump" between the two components in Eq. 1 that are locally decoherent.[1] Probability current flows from the first to the second component between times t_0 and t_f when the interaction is complete. We let $\psi(t)$ carry the full time dependence of the first component.[2]

Assume that an observer is looking at the detector from the beginning.

$$\Phi(t) = \exp(-iHt)\psi_i \otimes D_i B_i \tag{2}$$

where B_i is the initial brain state of the observer that is entangled with the initial state of the detector. This brain state is understood to include only higher order brain parts; that is, the physiology that is directly associated with consciousness after all image processing is complete. All lower order physiology leading to B_i is assumed to be part of the detector. The detector is now represented by a capital D, indicating that it includes the bare detector by itself *plus* the low-level physiology of the observer.

Following the interaction between the particle and the detector, the solution of the Schrödinger equation traditionally gives

$$\Phi(t \geq t_0) = \psi(t)D_0B_0 + D_1(t)B_1 \tag{3}$$

where B_0 is the observer's brain when the detector is observed to be in its ground state D_0, and B_1 is the brain state when the detector is observed to be in its capture state D_1. This says that there are two active brain states of this observer that simultaneously observe the detector, where one sees the detector in its ground state and the other sees it in its capture state. The equation therefore invites a paradoxical interpretation like that associated with Schrödinger's cat. This ambiguity cannot be allowed. The oRules (that replace the Born rule) must insure than this does not happen.

IV. THE RULES

The first oRule provides for the existence of a stochastic trigger. This alone distinguishes a quantum ontology from the ontology of classical physics.

oRule (1): *For any subsystem of n components in a system having a total square modulus equal to s, the probability per unit time of a stochastic choice of one of those components at time t is given by* $(\Sigma_n J_n)/s$*, where the net probability current* J_n *going into the* n^{th} *component at that time is positive.*

Before going on to oRule (2), we distinguish two different kinds of brain states.

B is a *realized* brain state – an active brain state that is understood to be conscious.

$\underline{B}$ is a *ready* brain state – an active brain state with the same content as B, except that it is *not* conscious. Ready brain states are understood to be the "basis states" of state reduction, and are always underlined.

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[1] Each component in Eq. 1 has an attached environmental term E_0 and E_1. These are orthogonal, insuring local decoherence. The equation appears to be a mixture because these terms are not shown. However, Eq. 1 (including the environmental terms) and others like it are fully coherent superpositions. In the following we will call them superpositions, reflecting their global rather than their local properties.

[2] Equation 1 can be written with coefficients $c_0(t)$ and $c_1(t)$ giving $\Phi(t \geq t_0) = c_0(t)\psi(t)d_0 + c_1(t)d_1$, where all three states $\psi(t)$, d_0, and d_1 are normalized throughout. We let $c_0(t)\psi(t)$ in this expression be equal to $\psi(t)$ in Eq. 1, and let $c_1(t)d_1$ be equal to $d_1(t)$ in Eq. 1.

oRule (2): *If an interaction gives rise to new components that are discontinuous with the initial state or with each other, then all of the new active brain states in the new components will be ready brain states.*
[**note:** Although solutions to Schrödinger equation change continuously in time, they can be "discontinuous" in other variables – e.g., the separation between the n^{th} and the $(n + 1)^{th}$ orbit of an atom with no orbits in between. Of course, atomic states are generally coherent, but a discontinuity of this kind can also exist between macroscopic states that are decoherent. For instance, the displaced detector states D_0 (ground state) and D_1 (capture state) are discontinuous with respect to detector variables. There is no eigenstate $D_{1/2}$ in between. These two detector states are a 'quantum jump' apart.]
[**note**: The *initial state* is the initial state of the system that appears in a given solution of Schrödinger's equation. A particular solution is defined by a unique set of boundary conditions. So Eqs. 2 and 3 are both included in the single solution that contains the discontinuity between d_0 and d_1, where Eq. 2 is the initial state. However, boundary conditions change with the collapse of the wave function, so the component that survives a collapse becomes the initial state of the new solution.]

oRule (3): *If a component containing ready brain states is stochastically chosen, then those states will become realized (i.e., conscious) brain states, and all other components in the superposition will be immediately reduced to zero.*
[**note**: The claim of an immediate (i.e., discontinuous) reduction is the simplest way of describing the collapse of the state function. The collapse is brought about by an instantaneous change in the boundary conditions of the Schrödinger equation, rather than by the introduction of a new 'continuous' mechanism of some kind. A continuous modification can be added later (with a modification of oRule 3) if that is seen to be necessary.]
[**note**: This collapse does not generally preserve normalization. That does not alter the probability in subsequent reductions because of the way probability per unit time is defined in oRule (1) – that is, it is divided by the total square modulus.]

The fourth oRule forbids transitions that go from a ready brain state to any other state. Negative probability/time is not physically meaningful. So a ready brain state (one of the basis states of reduction) is not permitted to have a negative current flow.

oRule (4): *If a component in a superposition is entangled with a ready brain state, then that component can only receive probability current.*

If an interaction does not produce ready brain components that are discontinuous with the old ones or with each other, then the Hamiltonian will develop the state in the usual way, independent of these rules. If the stochastic trigger selects a component that does not contain ready brain states, then there will be no oRule (3) state reduction.

V. APPLY TO INTERACTION

When these rules are applied to Eq. 3, we have

$$\Phi(t \geq t_0) = \psi(t)D_0B_0 + D_1(t)\underline{B}_1 \tag{4}$$

where the brain state in $D_1(t)\underline{B}_1$ is a ready state by virtue of oRule (2), so it is not conscious. Since there is only one conscious brain state in this superposition, a cat-like ambiguity is avoided. Equation 4 (with underline) now *replaces* Eq. 3.

Equation 4 is the state of the system before there is a stochastic hit that produces a state reduction. The observer is here consciously aware of the detector in its ground state D_0, for the brain state B_0 is entangled with D_0. If there is a capture, then there will be a stochastic hit on the second component in Eq. 4 at a time t_{sc}. This will reduce the first component to zero and convert the ready state in Eq. 4 into a conscious brain state according to oRule (3).

$$\Phi(t \geq t_{sc} > t_0) = D_1(t)B_1 \qquad (5)$$

Standard quantum mechanics (with the Born rules) gives us Eq. 3 by the same logic that it gives us Schrödinger's cat and Everett's many worlds. However with the oRules in effect, 'one' equation in Eq. 3 is replaced with 'two' equations in Eqs. 4 and 5. Equation 4 describes the state of the system *before* capture, and Eq. 5 describes the state of the system *after* capture.

VI. TERMINAL OBSERVATION

In another case, suppose the observer is not aware of the detector during the interaction with the particle as in Eq. 4, but he looks at the detector after the interaction is complete. During the interaction we then have

$$\Phi(t_f > t \geq t_0) = [\psi(t)d_0 + d_1(t)]\otimes X$$

where X is the unknown state of the observer prior to the physiological interaction.

After the interaction is complete and before the observer looks at the detector

$$\Phi(t \geq t_f > t_0) = [\psi(t)d_0 + d_1(t_f)]\otimes X$$

where there is no longer a probability current flow inside the brackets. When the observer finally looks at the detector at time t_{look}, we have

$$\Phi(t \geq t_{look} > t_f > t_0) = [\psi(t)d_0 + d_1(t_f)] \otimes X \qquad (6)$$
$$\rightarrow [\psi(t)D_0 + D_1(t_f)]B^b$$

where the physiological process (represented by the arrow) carries $\otimes X$ into B^b, d_0 into D_0, and d_1 into D_1 by a continuous classical progression leading from independence to entanglement. The brain state B^b is understood to be an inactive state at the *brink* of becoming active. There are as yet no conscious states in Eq. 6 because the process has not gotten beyond the brink state – i.e., all the brain states in Eq. 6 are inactive with respect to the detector.

During this process the observer will be unable to distinguish between the two detector states D_0 and D_1, which is why his brain is called inactive at this time. However, at some moment t_{ob} he will resolve the difference between these states, and when that happens a continuous 'classical' evolution will no longer be possible. The solution will then branch "quantum mechanically" into two components that separately recognize D_0 and D_1.

$$\Phi(t \geq t_{ob} > t_{look} > t_f > t_0) = \psi(t)\, D_0B^b + D_1(t_f)B^b \qquad (7)$$
$$+ \psi'(t)D_0\underline{B}_0 + D'_1(t_f)\underline{B}_1$$

where the components in the third row are zero at t_{ob} and increase in time, due to vertical current flow. The states in the third row are discontinuous from each other (i.e., D_0 and D'_1 are discontinuous) and contain active brain states. They are therefore required by oRule (2) to be ready brain states that are not conscious, so a cat-like ambiguity is again avoided.

With probability current flowing into the second row of Eq. 7, there is a probability equal to 1.0 that one of those components will be stochastically chosen. If the third component is chosen at a time t_{sc3}, then oRule (3) will give

$$\Phi(t \geq t_{sc3} > t_{ob} > t_{look} > t_f > t_0) = \psi(t)D_0B_0 \tag{8}$$

indicating that the terminal observer finds that the particle was *not* captured during the primary interaction.

If the fourth component is chosen at a time t_{sc4}, then oRule (3) will give

$$\Phi(t \geq t_{sc4} > t_{ob} > t_{look} > t_f > t_0) = D_1(t_{sc4})B_1 \tag{9}$$

indicating that the terminal observer finds that the particle *was* captured during the primary interaction. The probability of Eq. 8 plus Eq. 9 is equal to 1.0, thereby confirming the Born interpretation for this case.

VII. ANOMALY AVOIDED

The fourth oRule avoids a catastrophic anomaly if the primary interaction is complete at t_f *without* a capture, and before a second observer X looks at the detector.

$$\Phi(t \geq t_f > t_0) = [\psi(t)D_0B_0 + D_1(t_f)\underline{B}_1]\otimes X$$

After the second observer has observed the detector at t_{ob} (skipping t_{look}) we will have

$$\begin{aligned}\Phi(t \geq t_{ob} > t_f > t_0) = {}& \psi(t)D_0B_0B^b + D_1(t_f)\underline{B}_1B^b \\ & + \psi'(t)D_0B_0\underline{B}_0 + D'_1(t_f)\underline{B}_1\underline{B}_1\end{aligned} \tag{10}$$

where the second row is zero at t_{ob} and increases in time as a result of vertical current.

Assume that oRule (4) is not in effect. In that case the fourth component $D'_1(t_f)\underline{B}_1\underline{B}_1$ in Eq. 10 will be accessible to current from the second component. A stochastic hit at some time t_{sc4} would then be possible, yielding

$$\Phi(t \geq t_{sc4} > t_{ob} > t_f > t_0) = D_1(t_f)B_1B_1$$

This says that even though the first observer can testify that the interaction has been completed without a capture, both observers will experience a capture when the second observer comes on board – some time *after* the interaction is completed. That is absurd. The fourth oRule therefore plays the essential role in preventing absurdities of this kind.

VIII. OTHER CASES

In a previous paper (Ref. 1), a more complete coverage of the above interaction is considered. We look at an intermediate case in which the observer comes on board during the interaction, and we consider the more general case of a second observer in the picture. In another paper [6], the oRules are applied to the Schrödinger cat problem. There are two versions. In version I the cat is initially conscious and is made unconscious by an action initiated by beta decay. In version II the cat is initially unconscious and is made conscious by an alarm that is initiated by beta decay. In both of these cases the conscious experience of the cat is accurately and unambiguously predicted by the oRules, as is the experience of observer who is inside the system but outside the box containing the cat. This observer looks in the box at different times during the experiment and finds the cat in the correct state of consciousness.

IX. NO BORN RULE

In the epistemological model the observer can only look at the system instantaneously. He must then withdraw because he cannot become part of the system for any finite period of time. He cannot become continuously involved with the system that is being investigated. When discussing the Zeno effect, it is said that continuous observation can be simulated by rapidly increasing the number of instantaneous observations; but that is not really continuous.

On the other hand, the observer in an ontological model can *only* be continuously involved with the observed system. That's because it takes a finite amount of time for the flow of physiological current to bring the observer on board, and for the continuous classical physiological process to bring the observer to consciousness. So the epistemological observer makes instantaneous observations but cannot make continuous ones; and the ontological observer makes continuous observations but cannot make instantaneous ones. Evidently the Born rule requires the ontological observer to do something that he cannot realistically do. Epistemologically we can ignore this difficulty, but a consistent ontological model would not match a continuous physical process with continuous observation by using a discontinuous rule of correspondence. Therefore, an ontological model should not employ the Born interpretation that places unrealistic demands on an observer.

X. BETA COUNTER

When a beta counter is not being observed the equation of state is written

$$\Phi(t \geq t_0) = C_0(t) + C_1(t) + C_2(t) + C_3(t) + \ldots \text{ etc.}$$

where the components following C_0 are zero at t_0. The initial state C_0 is a counter that reads zero counts, C_1 reads one count, and C_2 reads two counts, etc. Immediately after t_0, current J_{01} flows from the 0^{th} component to the 1^{st} component, but not to higher order components because the Hamiltonian only connects the 0^{th} with the 1^{st}. However, current J_{12} will begin to flow into the 2^{nd} component as soon as the 1^{st} acquires amplitude. The 3^{rd} component will also receive current J_{23} when the 2^{nd} acquires amplitude; so after a time t, the distribution might look like Fig. 3.

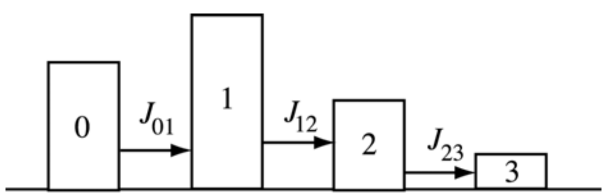

FIG. 3. Square moduli at time *t* - no observer

When a beta counter *is* observed, the equation of state is written

$$\Phi(t \geq t_0) = C_0(t)B_0 + C_1(t)\underline{B}_1$$

where $C_1(t)\underline{B}_1$ is zero at t_0 and increases in time. The brain state B_0 is an entangled conscious state that experiences the counter reading zero counts. The underlined state $\underline{B}_1$ is a ready brain state, so current cannot flow to the next component $C_2(t)\underline{B}_2$. Therefore, only J_{01} can initially flow from the 0^{th} to the 1^{st} component. This guarantees that the 1^{st} component *will* be chosen. That's because *all* of the current from the (say normalized) 0^{th} component flows into the 1^{st} component making

$\int J_{01} dt = 1.0$. The fourth oRule therefore assures us that the 1st component *will not be skipped over* as might happen when many components are available as in the superposition in Fig. 3.

After the first component is stochastically chosen, current J_{12} will flow into the second component as shown in the middle diagram in Fig. 4. This also leads with certainty to a stochastic choice of the 2nd component. That certainty is accomplished by the wording of oRule (1) that requires that the probability per unit time is given by the current flow J_{12} divided by the total square modulus at that moment. The total integral $\int J_{12} dt$ is less than 1.0 in Fig. 4, but it is restored to 1.0 when divided by the total square modulus. It is therefore certain that the 2nd component will be chosen.

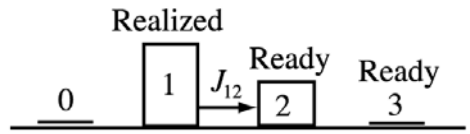

FIG. 4. Square moduli - with observer

And finally, with the choice of the 2nd component, the process will resume again. This leads with certainty to a stochastic choice of the 3rd component. The fourth oRule therefore insures that the counter will count in its proper classical sequence 0, 1, 2, 3, . etc., without skipping a count.

XI. PARALLEL CASE

Now imagine a parallel sequence of states in which the decay process may go either clockwise or counterclockwise as shown in Fig. 5. Each component includes a macroscopic piece of laboratory apparatus *A*, where the Hamiltonian provides for a clockwise interaction going from the 0th to the *r*th state and from there to the final state *f*; as well as a counterclockwise interaction from the 0th to the *l*th state and from there to the final state *f*. The Hamiltonian does not provide a direct route from the 0th to the final state. The apparatus is being observed by a brain state *B*.

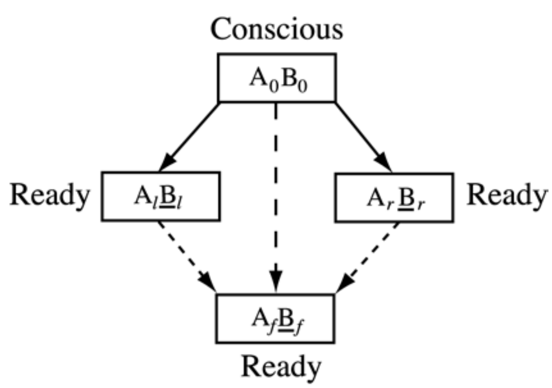

FIG. 5: Parallel decay with observer

After being turned on at time t_0, the apparatus becomes the superposition

$$\Phi(t \geq t_0) = A_0(t)B_0 + A_l(t)\underline{B}_l + A_r(t)\underline{B}_r$$

where the components following $A_0(t)B_0$ are zero at t_0, after which $A_0(t)B_0$ sends current to both $A_l(t)\underline{B}_l$ and $A_r(t)\underline{B}_r$. When one of these two is stochastically chosen, it will become realized, and will in turn send current to $A_f\underline{B}_f$. Probability current cannot initially flow from either of the intermediate states to the final state, for that would carry a ready brain state into another brain state – in violation of oRule (4). The dashed lines in Fig. 5 indicate the forbidden transitions.

The result of oRule (4) is therefore to force the system into a classical sequence that goes either clockwise or counterclockwise. Without it, the system might make a second order transition (through one of the intermediate states) to the final state, without one of the intermediate states being realized. That is familiar behavior when the system is microscopic, but it should not be the case when the system is macroscopic. Here again, because of oRule (4) this macroscopic system cannot skip a step. It will complete a normal sequence over one or the other pathway.

XII. CONTINUOUS VARIABLE

In the above example an observer plus oRule (4) guarantees that none of the finitely separated intermediate steps are passed over. On the other hand, if the variable itself is classical and continuous, then continuous observation is possible without the necessity of stochastic jumps. In that case we do not need oRule (4) or any of the oRules (1-4), for they do not prevent or in any way qualify the motion.

However, a classical variable may require a quantum mechanical jump-start. For instance, the mechanical device that is used to seal the fate of Schrödinger's cat (e.g., a falling hammer) begins its motion with a stochastic hit. That is, the decision to begin the motion (or not) is left to a β-decay. In this case, the presence of an observer (looking at the hammer) forces the motion to begin at the beginning, insuring that no value of the classical variable is passed over, so the hammer will fall from its initial angle with the horizontal. Without oRule (4), the hammer might begin its fall at some other angle because probability current will flow into angles other than the initial one. With an observer plus oRule (4) in place, no angle will be passed over.

XIII. GROUNDING THE SCHRÖDINGER SOLUTIONS

Traditional quantum mechanics is not completely grounded in observation inasmuch as it does not include an observer. The epistemological approach of Copenhagen does not give the observer a role that is sufficient for him to realize the full empirical potential of the theory; and as a result, this model encourages bizarre speculations such as the many-world interpretation of Everett or the cat paradox of Schrödinger. However, when rules are written that allow a conscious observer to be given an ontologically complete role in the system, these empirical distortions disappear. It is only because of the incompleteness of the epistemological model by itself that these fanciful excursions seem plausible[3].

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[3] Physical theory should be made to accommodate the phenomena, not the other way around. Everett goes the other way around when he creates imaginary phenomenon to accommodate traditional quantum mechanics. If the oRules were adopted in place of the Born rule, these flights of fantasy would not be possible.

IXV. STATUS OF THE RULES

No attempt has been made to relate conscious brain states to particular neurological configurations. The oRules are an empirically discovered set of macro-relationships that exist on another level than micro-physiology, and there is no need to connect these two domains. These rules preside over physiological detail in the same way that thermodynamics presides over molecular detail. It is desirable to eventually connect these domains as thermodynamics is now connected to molecular motion; and hopefully, this is what a covering theory will do. But for the present we are left to investigate the rules by themselves without the benefit of a wider theoretical understanding of state reduction or of conscious systems. There are two rule-sets of this kind, the oRules of this paper plus the nRules in Ref. 5.

The principle difference between the nRules and the oRules is that the former allow both an observer and an objective type measurement – i.e., the presence of an observer isn't necessary to collapse the state under the nRules. This is achieved by treating *all* states as having a dual property – realized and ready. For instance, there may be realized detector states and ready detector states. The rules are otherwise similar. The fourth nRule forbids current from being transmitted by any ready state.

The question is, which of these two rule-sets is correct (or most correct)? Without the availability of a wider theoretical structure or a discriminating observation, there is no way to tell. Reduction theories that are currently being considered may accommodate a conscious observer, but none are fully accepted. So the search goes on for an extension of quantum mechanics that is sufficiently comprehensive to cover the collapse associated with an individual measurement. I expect that any such theory will support one of the ontological rule-sets, so these rules might serve as a guide for the construction of a wider theory.

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