# Response to "On Russell's Derivation of Quantum Mechanics" by Youness Ayaita

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**2.1:** A paper by Patrick van Esch (arXiv:quant-ph/0505059) indicates that the Born rule appears to be independent of the other axioms of quantum mechanics.

**2.2:**

- I identify what is sometimes known as the "wavefunction of the universe" as the observer moment. For practical QM calculations, one usually assumes that some subsystem of the universe is seperable from its environment, or at least sufficiely so for approximate purposes. Let $\psi = \psi_S + \psi_E$ for $\psi_S \in S$, the Hilbert space describing the system, and $\psi_E \in E$, the Hilbert space describing the rest of the universe. $S$ is perpendicular to $E$, ie $< \psi_S|\psi_E >= 0, \forall \psi_S \in S, \psi_E \in E$. Furthermore, the Hamiltonian is block diagonal on these subspaces, $H = H_S \oplus H_E$.

  So yes, observer moments have a lot of stuff that have little to do with the system, but then so does $\psi = \psi_S + \psi_E$.

  As for other observers with different obersver moments, if they share a reality, they will agree that some part of their state vectors are identical, ie $\psi_S = \psi'_S$, but not $\psi = \psi'$. The part of $\psi$ not in agreement must correspond to the non-shareable aspects of observer moments, things like qualia and so on. Physics is only interested in that part of $\psi$ which is shareable, of course, so will always be working with a subspace of the full Hilbert space.

- Objectivity of the physical state vector. "Physics succeeds in meaningfully applying the postulates of QM even to periods of time during which the human rase did not exist". How do we know this? All we can say is that the postulates of QM describe the trace record of a presumed past when humans didn't exist. The trace record exists in the here and now, and I would interpret things as saying that it is in a superposition of alternative pasts until such a time as a measurement occurs, just as it is with experiements conducted in the present day.

  A very important consequence of the interpretation I develop, and it also occurs in Bruno's COMP work, is that we must abandon classical notions of "objective reality", and instead work with self-consistency of observational data.

I realise that this conclusion is going to be a hard sell. But it is what the data is telling us. There are some attempts by David Deutsch and other to reconcile the Multiverse with a notion of objective reality, but my gut feeling is that these programmes will ultimately fail.

- Kolmogorov axioms. These are basically definitional — they define what we mean by the term "probability". The Kolmogorov axioms describe the classical notion of probability — other axiom systems have been proposed to generalise the notion of probability, and maybe one of these systems is a better reflection of how to measure likelihood of outcomes (the Kolmogorov axioms are basically used to put flesh on the PROJECTION postulate), but for the present the Kolmogorov system is the least controversial formulation.

  Interestingly, one of the reviewers of my original paper expressed disbelief that quantum mechanics could be founded on classical probability, and that a non-classical formulation is needed. Well my derivation essentially stands as a counter example to that disbelief, and one needs to find a mathematical flaw my argument in order hold up that disbelief.

**2.3:**

- What is the meaning of $n\psi_A$? It is defined as $n\psi_A = \psi_A + \psi_A + ...\psi_A$ (where + is done $n-1 \in \mathbb{N}$ times). Of course, if $n$ is not 0 or 1, then it is no longer the simple ensemble we discussed in terms of the PROJECTION postulate. Neither is $\psi_A + \psi_B$ where $A \cap B \neq \emptyset$. It should be noted that these new extended objects cannot necessarily be written in the form of $\psi_X$, for some set X.

  Similarly, we extend the function $p_\psi$ to the new set containing such things as $n\psi_A$. Obviously, $p_\psi$ is no longer a probability, except when it is applied to $\psi_A : A \subset S$.

  Thus far we have only done mathematical stuff. What is interesting is whether there is any meaningful physical interpretation to something like $n\psi_A$. I do interpret this as saying multiple observers observing a given observer moment. You raise an extremely interesting objection that this makes me a duplicationist in spite of my protestations to the contrary. Perhaps so — I'm not convinced it is as simple as that though. Psychologically, one is not aware of one's measure, which is an important consideration when considering complex valued measures. Anyway, it is a point of discussion.

- The probabilities physicists measure are the $p_\psi$ values applied to a basis set $\psi_A$, $A \subset S$. These are what we compute by Born's rule.

- Intersubjective consistency is an interesting fact about the world which demands explanation. I have something about it starting on page 164 of my book which outlines a possible explanation. However, much remains to be done, and we may well need more results coming in from cognitive science.

- The set of all infinite length bitstrings is indeed a maximal candidate for the reference state $\psi$. It is the set of all possible observer moments one observer can experience (including inexperiencable ones). But you must also include all possible observers, effectively forming a Cartesian product of observers and possibilities. And this is what gives rise to the Hilbert space structure.

- $p_\psi$ is actually *not* a measure. A measure is a function defined over sets, but objects like $\psi_A + \psi_B$ are actually more of a multiset when $A \cap B \neq \emptyset$. In fact it is a multiset precisely when the coefficients are natural numbers ($\mathbb{N}$). What we are arguing is that $p_\psi$ is a *linear generalisation* of a probability function defined over sets. The object $a\psi_A + b\psi_B$ is to be interpreted as describing the situation of $a$ observers observing outcome $A$ and $b$ observers observing outcome $B$. It is clear that $a$ and $b$ should be drawn from a measure. What is not clear is what other properties they should satisfy. You suggest that they must be restricted to the natural numbers. Intuitive yes, but also in contradiction with reality. In my book I give a rather lame argument as to why they must satisfy just the field axioms, however I do consider this question open. I think it would be extremely interesting if someone worked out quantum theory based on quaternions to see if there is any difference from complex valued QM, and if there were, whether quaternion QM is already falsified by experiment.

**2.6:**

- "I cannot see how it can be true that the $\psi_{\{a\}}$ form a basis of $V$". Having reread my appendix, I agree that this is a fair call. Unfortunately, it appears that I have used the label $V$ to refer to several different things. Firstly, I use it to refer to the set of all observer moments, for which your comment is patently true. Next I define $V$ as the linear span $V = \mathcal{L}(\psi_{\{a\}})$, for which it is trivially true that $\psi_{\{a\}}$ form a basis set. However, these two $V$s are only equivalent when $\psi$ is the everything ensemble, which I probably had in mind when writing this, but the Born's rule derivation applies even when $\psi$ is not the everything ensemble.

  The $U$ is introduced rather mysteriously here too. I think it refers to the set of all $\mathcal{P}_A(\psi)$, given that I use $V$ in "Why Occams Razor" to refer to that object. I apologize for this notational confusion.

- You raise the extremely interesting point of what happens when we have two sets of observables $S$ and $T$, such that $|S| \neq |T|$. It is certainly true that $V_S \equiv \mathcal{L}(\{\psi_a | a \in S\}) \neq V_T \equiv \mathcal{L}(\{\psi_a | a \in T\})$ as you point out. It must also true that the reference state $\psi = \sum_{a\in S} \psi_a$ is not the same reference state $\psi = \sum_{a\in T} \psi_a$. This I think makes sense — if observer S decides to measure according to observable S, then clearly e is in a different observer moment to one deciding to measure according to observable T.

- I wasn't previously aware of Gleason's theorem. A superficial look at the Wikipedia entry indicates that there is some connection with my derivation of Born's rule. I've saved the paper by Pitowski that the Wikipedia article mentions, and add it to my reading stack.

**2.7:**

- If all information required to determine the state of the system at time $t'$ also existed as part of state of the system at time $t$, then $\psi(t')$ is deterministically given by $\psi(t)$ (it cannot be anything other than $\psi(t')$. This is all conservation of information means.
- Time is assumed to be continuous purely for the purposes of making contact with standard quantum theory. I know of no reason why time should be continuous, and indeed discuss several alternatives in my book. I seem to have omitted this qualification in appendix D of my book — it is there in "Why Occams Razor". It would indeed by interesting to explore different models of time (through the theory of timescales) to see how QM differs (in same light as my comments on quaternionic QM).